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AGRICULTURAL UTILIZATION
of
SEWAGE EFFLUENT AND SLUDGE

An Annotated Bibliography

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Contents

Abstract -- iv

Introduction -- 1

Annotated Bibliography:

1. Sewage Effluent as an Agricultural Water Resource:
    - Discussion -------------------------------- 3
    - Abstracts:
        - Prior to 1951 -------------------------- 4
        - 1951–1955 -------------------------- 11
        - 1956–1960 -------------------------- 17
        - 1961–1965 -------------------------- 22
2. Agricultural Value of Sewage Sludge:
    - Discussion -------------------------------- 28
    - Abstracts:
        - Prior to 1951 -------------------------- 30
        - 1951–1955 -------------------------- 33
        - 1956–1960 -------------------------- 35
        - 1961–1965 -------------------------- 37
3. Land Disposal of Liquid Wastes–Pollution Abatement and Effects on Soil Properties:
    - Discussion -------------------------------- 39
    - Abstracts:
        - Prior to 1951 -------------------------- 40
        - 1951–1955 -------------------------- 43
        - 1956–1960 -------------------------- 49
        - 1961–1965 -------------------------- 52
4. Sanitary Aspects of Waste Water Utilization:
    - Discussion -------------------------------- 59
    - Abstracts:
        - Prior to 1951 -------------------------- 60
        - 1951–1955 -------------------------- 63
        - 1956–1960 -------------------------- 70
        - 1961–1965 -------------------------- 72
5. Industrial, Recreational, and Other Water Reuse Applications:
    - Discussion -------------------------------- 74
    - Abstracts:
        - Prior to 1951 -------------------------- 76
        - 1951–1955 -------------------------- 76
        - 1956–1960 -------------------------- 77
        - 1961–1965 -------------------------- 81

Author Index -- 87

Abstract

The effluent and sewage sludge from municipal and industrial treatment plants is a source of water and nutrients for agricultural uses. Considering its potential, only a few instances of agricultural uses of waste water in crop production have been recorded. Most of the literature on this subject is by scientists in the sewage disposal field.

This report brings together about 300 annotated references on the agricultural uses of sewage effluents and sludge. Such uses aid crop production, but also make use of water that would have been wasted, decrease the pollutant load on the receiving streams, and preserve the normal stream flow for downstream uses.

Introduction

The need to conserve *all* our water resources is becoming increasingly evident. New water cannot be manufactured! We are forced to depend upon the fixed supply to meet all our water needs. Intelligent and comprehensive planning for the conservation, control, use, and reuse of water is a must if we are to meet the heavily increasing demands on our water resources.

Future water needs for agriculture are of major concern. Benefits to agriculture can come from the use/reuse of water that is normally wasted to surface drainage and receiving streams. In arid regions, waste water and sewage effluents at times make up most of the flow in smaller streams, resulting in serious pollution problems for downstream water users. Using such waste waters for agricultural purposes, therefore, achieves two primary objectives: 1) it makes use of water that is normally wasted and 2) it decreases the pollutant load on the receiving stream and preserves the normal stream flow for beneficial uses downstream. For example, the reuse of treated waste waters for irrigation of such areas as parks and golf courses has been proved entirely feasible, particularly in arid regions.

When we consider the potential of waste water reuse, comparatively few instances of agricultural use of waste water in crop production have been recorded. More often, the purpose has been the convenient disposal of waste water rather than its maximum utilization. Agriculturists may be overlooking a valuable water source that could be used much more efficiently than is presently being done.

Interestingly, the bulk of the literature covering agricultural use of reclaimed waste waters comes not from agricultural scientists, but from those working in the sewage disposal field.

A primary purpose of this report is to bring many of these references together hopefully to stimulate interest among crop and soil scientists in the use of sewage effluents that are presently being wasted to surface streams.

This report represents the results of a literature survey and the preparation of abstracts for the references found. These are brought together in the form of an annotated bibliography for the readers' ready reference.

The bibliography is divided into five major subject headings:

sewage effluent as an agricultural water resource
agricultural value of sewage sludge
land disposal of liquid wastes
sanitary aspects of waste water utilization
industrial, recreational, and other water reuse applications

The references pertinent to each subject are grouped, with their abstract, under that heading. At the beginning of each section, a short discussion describes the scope of references included in that subject heading. Many of the works abstracted cover more than one subject area. These are placed in the section which seemed most appropriate for the subject matter given the most emphasis by the author.

The abstracts in each section are arranged, first, in chronological order (based generally on 5-year periods) and, second, in alphabetical order by author's surname for each chronological grouping. An author index is included at the end of the report.

1

Sewage Effluent as an Agricultural Water Resource

Waste water arising from domestic and industrial use is generally unfit for further use without some treatment. Even though the increase in solids content because of use is small, it is the nature of the added material rather than the amount that makes treatment necessary.

The past century has seen a great advance in technology and the health sciences, resulting in sewage treatment plants which produce effluents that are both safe and suitable for irrigation of certain crops. The type of treatment by a sewage treatment plant determines the degree to which the suspended solids are removed from the sewage. Primary treatment by sedimentation may remove only 25 to 40 percent of the suspended solids. Additional treatment by trickling filtration and secondary sedimentation or by the activated sludge process may remove as much as 95 percent of the suspended solids. Chlorination of the clarified effluent from a modern sewage treatment plant produces reclaimed water that is safe for many reuse applications. It may be particularly suited to agricultural applications due to the soluble phosphates and nitrates that remain after treatment. The quantities of these nutrient materials remaining vary widely and should be determined for any effluent considered for reuse.

The application of sewage effluent to agricultural land may serve two primary purposes: (1) to promote the growth of crops, and (2) to further treat the applied effluent. The effluent must be adequately treated prior to use on agricultural areas to avoid odor and other serious nuisance problems.

Proper sanitary management dictates that the constant flow of effluent be utilized at all times. During periods of heavy rainfall and/or when crops are not being grown, it may be necessary to provide adequate storage in lagoons or lakes to hold the effluent in reserve for times when it can be properly utilized by the crops.

Modern methods of irrigation management must also be employed for the most efficient use of the available supply. The water intake rate and storage capacity of the soil profile should be considered, as well as the type of crop to be grown, in determining the area required for the amount of water to be applied. Irrigation must be intermittent and over-irrigation must be avoided if maximum efficiency is to be achieved.

Several research reports included in this bibliography have considered the fertilizing value of sewage effluent. It is generally agreed that some value is obtained, but this is usually not adequate as a complete nutrient supply. This again would depend to a great extent on the soil and the requirements of the crop itself. The requirements should be considered for each individual set of circumstances.

Irrigation is normally practiced in areas where rainfall is not sufficient during the growing season for maximum crop production. If irrigation is desirable, the use of sewage effluent makes use of water that is normally wasted; it contributes to the economy of an area by increasing crop yield; and, at the same time, reduces the pollution load imposed on normal stream flow of the area.

Abstracts

Prior to 1951

1. ANONYMOUS. 1940. Biofiltration Effluent Used for Irrigation at Santa Paula. *Engr. News-Record* 125:834.

Effluent from a biofiltration sewage treatment plant serving 12,000 residents in Santa Paula, California, is used to irrigate orchard lands adjacent to that city. The city is proud of its attractive and useful plant which is capable of converting sewage into irrigation water.

2. ANONYMOUS. 1941. Combining Old and New in Sewage Disposal. *Engr. News-Record* 126:811-812.

Using a recently developed combination flocculation-clarifier unit, which gives high efficiency in the removal of suspended solids, Bakersfield, California supplements this pretreatment of its sewage with broad irrigation. Thus, the city secures complete treatment of its sewage and at the same time irrigates 600 acres of pasture land.

3. ANONYMOUS. 1946. Sewage Farming at Tuscon. *Sewage Wks. Jour.* 18:1211.

Average flow of 4 mgd is used to irrigate about 300 acres of city-owned land with primary treatment effluent. Crops of oats, barley, and ensilage are rotated on the land. The crops yield a net profit of $3,000 to $5,000 per year to the city.

4. ABBOT, A. L., ET AL. 1948. Grazing of Cattle on Sewage Farms and Disposal Works. *Public Health* (South Africa), Mar. 1948, p. 76-88. Abst: *Sewage Wks. Jour.* 21:185-186.

Quoting from the abstract: "It is the consensus of opinion that consumption of sewage effluents by cattle has no harmful effect on milk production or disease incidence, and introduces no possibility of milk contamination except indirectly from unhygienic dairy procedures. The positive advantages of irrigating grazing land with sewage include utilization of valuable fertilizing material and irrigating water as well as providing a satisfactory sewage disposal method that produces revenue to partially offset sewage works costs."

Procedures followed at the Cape Town sewage works are given.

5. GOODWIN, EARL H. 1935. Sewage Irrigation in Texas. *Pub. Wks.* 66:23. Abst: *Sewage Wks. Jour.* 7:589.

Since 1900, San Antonio has utilized a part of its sewage effluent to irrigate up to 3500 acres. At present, about 47 plants in Texas use irrigation as a means of treatment and disposal.

Spray, border, and furrow methods are used to irrigate grains, grasses, cotton, alfalfa, nuts, and citrus. Porous sandy soils seem to be most suitable.

Careful supervision is required so that soil type and crops form a compatible combination for the efficient utilization of the effluent.

6. HALAMEK, FERDINAND. 1948. Agricultural Utilization of Domestic Sewage in Europe and U.S.A. *Vestnik Ceskoslov. Akad. Zem.* 22:396-402. *Biol. Abst.* 23:3092.

The present status of sewage irrigation and the utilization of fertilizing ingredients in sewage and sewage sludge in Europe and U.S.A. is presented. Germany uses sewage irrigation and often overlooks the hygienic problem. In Britain the use of sewage as a fertilizer is decreasing. In the U.S.A. sewage irrigation is practiced only in the southwestern states and, there, hygienic regulations are severe. Directions are given for proper management of sewage irrigation.

7. HARRELL, RILEY B. 1939. Sewage Irrigation as a Method of Disposal. Proc. 21st Texas Water Works and Sewage Short School, p. 121-123. Abst: *Sewage Wks. Jour.* 12:1019.

The author describes sewage irrigation as practiced by the city of Munday, Texas. Use of row crops is recommended for better weed control. Cotton is most satisfactory crop. In 1934, 24 acres of irrigated land produced 23 bales of cotton. Dry land produced less than one-third bale per acre of poorer quality cotton. Serious problem of effluent disposal has been solved by irrigation.

8. HUTCHINS, WELLS A. 1939. Sewage Irrigation as Practiced in the Western States. *USDA Tech. Bull.* No. 675, 60 pages.

A comprehensive review of the agricultural use of sewage as it was practiced in the Western States during the 1930's. Differentiates between "sewage irrigation" and "sewage disposal." The author points out that water not safe enough to discharge to streams is not safe for general irrigation use without the possibility of becoming a health hazard. Therefore, sewage for irrigation use requires pretreatment.

Some of the important topics discussed are sewage as a source of irrigation water supply, use of water, irrigable lands, crops, safeguards and regulations of public health authorities, salts in sewage effluents, sewage water rights, and the economic feasibility of sewage irrigation.

A list of areas where crop irrigation with sewage is practiced is included in the appendix. A bibliography includes 52 entries.

9. HYDE, CHARLES G. 1929. Sewage Disposal Practice in Europe. *Western Const. News* 4:345-352. Abst: *Sewage Wks. Jour.* 1:647-650.

The author reports on inspection tour of 28 sewage treatment plants in Great Britain and Germany. The treatment processes observed are described. A number of plants employed "broad irrigation" as a means of treatment. The sewage of Berlin, Paris, and Milan is used to irrigate crops.

10. JACKSON, LEON W. 1947. Sewage Plant Sells Sludge and Effluent. *Engr. News-Record* 139:56-58.

Trickling filters, 175 ft. in diameter, feature the design of a new sewage treatment plant for the city of Riverside, California. The plant is so arranged that the entire flow through the plant is by gravity. Treated effluent will be used for irrigation purposes and dried sludge will be sold for fertilizer. Complete design and engineering data for the new plant are given.

11. KREUZ, C. A. 1935. Utilization of Domestic Sewage and Industrial Wastes by Broad Irrigation. *Gesundheits Ing.* 58:190. Abst: *Sewage Wks. Jour.* 8:348-349.

The agricultural use of sewage assists in producing foodstuffs high in protein. Plant nutrient content is valuable as fertilizer constitutents. Difficulties encountered with broad irrigation are discussed. Waste treatment by soil filtration with agricultural use of the land in the second year is recommended.

12. MALOCH, M. 1947. The Effect of Sewage Water on the Yield and Quality of Grassland. *Sborn. Csl. Akad. Zemed.* 19:57-107. *Soils and Fertilizers* 13:364 (2021), 1950.

Application of sewage water for 3 years to grassland raised the hay yield by 132.9 percent and the yield of crude protein by nearly

300 percent. Additions of superphosphate, Ca and K salts to the sewage waters gave even higher increases. There was evidence of residual action of N from the sewage, and its effect in increasing the resistance of the grasses to summer drought was very marked.

13. MITCHELL, GEORGE A. 1930. Sewage Farm Displaces Filter Beds at Vineland, New Jersey. *Engr. News-Record* 104:65.

Vineland was one of the first cities to adopt sewage irrigation of crops as a means of disposal. The raw sewage was piped a distance of 2.5 miles to a sandy area where a settling tank and sludge-drying beds were built. The effluent was used to irrigate 50 acres of recently cleared river sand. The second year produced good yields of sweet potatoes, sweet corn, eggplant, and rhubarb on this previously sterile soil with the use of no fertilizer except sewage.

14. MITCHELL, GEORGE A. 1931. Observations on Sewage Farming in Europe. *Engr. News-Record* 106:66-69.

Sewage farms were visited in Berlin and other German cities, Paris, Moscow, Edinburgh, and four towns in England. Some of the cities of Germany have used this form of sewage disposal for over 60 years, and very successfully. Cases are cited where very poor sandy land has been converted to good, productive farmland by sewage irrigation. Details of sewage farm operations at Berlin, Paris, and Moscow are given.

In England, sewage irrigation of crops is decreasing due to growth of cities, and because suitable areas for expansion of the farms are difficult to find. Tighter, less sandy soils than on the continent require larger areas for suitable sewage farming practices.

Experience has shown that sewage farming poses no serious threat to public health. The irrigation of crops with sewage effluent is a method of disposal well worth considering in the United States.

15. MITCHELL, GEORGE A. 1937. Municipal Sewage Irrigation. *Engr. News-Record* 119:63-66.

A sewage irrigation farm in use since 1928 at Vineland, New Jersey provides disposal facilities for a population of 8,000 and aids crop production in poor soil. A detailed description of the operating methods is given. Distribution system details include land slope and flow, land preparation, and crops grown. Revenue and cost data are included.

16. PILLAI, S. C., RAJAGORALAN, R. and SUBRAHMANYAN, V. 1945-1949. Investigations on Sewage Farming. *Progress Reports Appearing in Indian Inst. of Sci.* 1945, 1946, 1947, 1948, 1949. *PHE Abst.* 31:S:73 (1951).

Studies were made on the use of sewage as fertilizer and for irrigation in India, including response of different crops, fertilizing value of diluted sewage and mixtures of sewage and textile wastes, the effect of the nature of the soil in determining the response of crops to sewage, the effect of application of sewage during different stages of plant growth, the residual effect on subsequent crops, the decomposition of sewage in the soil, the accumulation of unavailable phosphorus in the soil, drainage from sewage-irrigated soils, the bacterial quality of crops, the cause and cure of sewage-sickness of soil, the use of aerated sludge as fertilizer and for feeding animals, mechanisms of sewage oxidation, and the culture of fish in sewage effluents. Detailed results of the investigations are given in tables.

17. POUQUET, F. 1939. Sewage Purification in the Parisian Area. Construction of a Biological Treatment Works at Acheres. *Trauvaux* 79: (Mar.) 87-95. Abst: *Sewage Wks. Jour.* 11:719-720.

A network of sewers is under construction which will terminate in the agricultural area of Acheres. Sewage of Paris is presently spread on farms in four different regions at an average rate of 132 million gpd. Future growth estimates predict increased volume to as much as 634 million gpd. Due to limited areas for expanding farm operations, biological treatment is being planned to take care of excess flow. Sewage irrigation has proved satisfactory. Liquid sludge from the new activated-sludge treatment plant will be disposed of on farm lands.

18. RINEY, W. A. 1928. Irrigation with Sewage Effluents. *Sewage Wks. Jour.* 1:108.

Abilene, Texas disposes of effluent from septic tanks by contracting with farmers to use the effluent for irrigation of row crops.

19. SEGAL, A. 1950. Sewage Reclamation at Fresno, California. *Sewage and Ind. Wastes* 22:1011-1012.

The city of Fresno owns and operates a municipal farm, 1,292 acres in area, where the treated sewage effluent is used for the irrigation of crops. In addition to 600 acres of grassland, the water is used to irrigate such forage crops as alfalfa, sudan grass, and kaffir corn. A herd of over 600 fine Hereford cattle are maintained on the farm. For the fiscal year ending June 30, 1949, the city realized an operating profit of $9,346.

In 1921, the city owned only 812 acres, and disposal of sewage effluent created a serious problem with a high water table only about 2 ft. below the surface. Law suits were filed by adjacent landowners for waterlogging and flooding adjacent lands. To correct this situation, some of the land was lagooned, and 9 wells were installed from 200 to 300 ft. deep with no perforation of the casing less than 100 ft. from the surface. The wells were successful in lowering the water table. Water from the wells was diverted to the Fresno Irrigation District for use in its system. Increased irrigation agriculture and installation of many wells in the area have helped to improve the groundwater level and facilitate the percolation of plant effluent into the underground basin.

20. SHREIER, FRANZ. 1950. Problems in Sewage Farming. *Berichte der Abwassertechnischen Vereinigung* No. 2, 118. Abst: *Sewage and Ind. Wastes* 25:241.

The problems considered are pretreatment, changes in farming methods, zoning of urban areas, hygiene, biology, and economics. Pretreatment is considered to be imperative. Changes in farming methods may involve new capital investments. Sewage farming should not be permitted near water treatment plants. Odors may interfere in urban areas. Spraying onto grazing areas is hygienically, biologically, and economically the best means of sewage utilization.

21. STOKES, W. E., LEUKEL, W. A., and BARNETTE, R. M. 1930. Effect of Irrigation with Sewage Effluent on the Yields and Establishment of Napier Grass and Japanese Cane. *Jour. Amer. Soc. Agronomy* 22:540-548.

Septic tank effluent was used to irrigate forage crop plants for four years. Yields were higher from the sewage-irrigated plots than from nonirrigated and the city-water irrigated plots. Analyses of typical sewage effluent showed the presence of considerable quantities of nitrogen compounds. Analyses of soil following irrigation showed only slight increases in nitrogen content.

22. SYMPOSIUM. 1935. Experiences with Sewage Farming in Southwest United States. *Amer. Jour. Pub. Health* 25:119-127. Abst: *Sewage Wks. Jour.* 7:320-322.

1. Texas, V. M. Ehlers: Chief concerns have been to dispose of sewage without nuisance and reduce stream pollution. Cropping is secondary, although value of waste water for irrigation is apparent. In Texas, 68 cities use land disposal, 34 grow crops, and 2 use subsurface irrigation. Total area being irrigated for crops is about 4,500 acres. A guide for operators and designing engineers is given.

2. Arizona, F. C. Roberts, Jr.: Describes land disposal operations at Tucson and Casa Grande. Data are given.

3. California, E. A. Reinke: Gives history of crop irrigation with sewage in California. At present, 53 cities irrigate cultivated crops, 9 irrigate native crops, and 28 use land disposal with no crops.

State Department of Health regulations concerning use of sewage effluent for irrigation are discussed. These include types of crops and sewage treatment required.

23. WIERZBICKI, JAN. 1949. Disadvantages and Advantages of Sewage Disposal in Connection with Agricultural Utilization. *Gaz, Woda i Tech. Sanit.* (Polish) 23:198. Abst: *Sewage and Ind. Wastes* 22:578-579.

Agricultural use of sewage in Europe dates back to 1559. Rapid growth of cities and restricted land areas later led to overloading and unsatisfactory results. Where adequate areas were available, the results were satisfactory.

Disadvantages include large land area needed, suitable soil porosity required, must be located downstream from water source, and pumping cost if it must be transported some distance.

A major benefit is to the economy of an area. Arid acres can be made productive. Other advantages are the fertilizer value and increasing humus content of soil. Gravity flow to the fields is best.

24. WIERZBICKI, JAN. 1949. Modern Methods in the Agricultural Utilization of Sewage. *Gaz, Woda i Tech. Sanit.* (Polish) 23:298. Abst: *Sewage and Ind. Wastes* 22:969-970.

Natural sloping terrain of at least 2 percent should be used. Loading rates are 25 to 50 acres per 1,000 population. Large areas are required.

Any method normally used for applying irrigation water can be employed. Spraying has many advantages, but a clarified effluent is required. Fish ponds or forested areas may be utilized to take care of the excess flows.

25. WIERZBICKI, JAN. 1949. Sewage Farming at Ostrow Wielkopolski. *Gaz, Woda i Tech. Sanit.* (Polish) 23:387. Abst: *Sewage and Ind. Wastes* 22:971-972.

Disposal by sewage farming dates back to 1911 at fields 2.5 miles from the city. The farm operation is described in detail, giving acres used, daily flow, treatment processes, and hay and silage yields. The farms are well managed, show a definite profit to the city, and benefit the local farmers by providing them with excellent hay.

26. WIERZBICKI, JAN. 1950. Economics of Sewage Disposal in Connection with Agricultural Utilization. *Gaz, Woda i Tech. Sanit.* (Polish) 24:193. Abst. *Sewage and Ind. Wastes* 22:1508.

European experience with sewer farms is summarized. Developments leading to the distribution of sewage on irrigation fields and factors affecting their cost of operation are considered. Hay yields were increased 5-8 fold. Increases in other crops are also reported.

27. WIERZBICKI, JAN. 1950. Effect of Geographical Factors on the Widespread Agricultural Use of Sewage. *Gaz, Woda i Tech. Sanit.* (Polish) 24:407. Abst: *Sewage and Ind. Wastes* 23:941.

Surface irrigation in England is not feasible because of high annual rainfall, small irrigable areas, large concentrations of population, and low nutrient value of effluents. Sewage irrigation has developed rapidly in central Europe due to inadequate rainfall, more permeable soils, and high nutrient content of sewage.

High temperatures and low rainfall in the western U.S. favor irrigation with clean water or sewage. The potential for sewage irrigation in Poland is excellent. Gravity flow to the farm is favored, although moderate pumping costs may be permissible.

28. WILCOX, L. V. 1948. Agricultural Uses of Reclaimed Sewage Effluent. *Sewage Works Jour.* 20:24-35.

Water is the principal factor limiting development in many arid regions. Every effort should be made to prevent contamination and promote the use of effluents for irrigation purposes. The properties that determine the quality of water for irrigation use are discussed, and several examples of typical irrigation waters are given. Permissible limits of concentration, percent sodium, and boron concentration are given for several classes of irrigation water. The analyses of a number of sewage effluents are shown and their qualities considered. A number of substances are listed that might appear as contaminants in sewage effluents and that are known to be toxic to plants. Boron is the most common toxic contaminant. Pesticides, certain plant hormones, salts of heavy metals, and many organic chemicals would render effluents unfit for irrigation use. Great care should be exercised in permitting disposal of industrial wastes into sewer systems if the effluent is to be used for irrigation water.

1951 — 1955

29. ANONYMOUS. 1951. Water for Irrigation Use. *Chem. Eng. News* 29:990. Abst: *Sewage and Ind. Wastes* 23:1214.

A report on papers presented at a symposium. The quality of irrigation water is very important. Availability of the water to plants decreases sharply with increasing salt concentration, because of the increasing osmotic pressure. Specific ions may accumulate sufficiently to become toxic to certain plants. Boron is highly toxic to plant growth at concentrations greater than about 3 ppm. The sodium ion tends to cause soil clogging, whereas calcium and magnesium ions tend to make a soil permeable. Thus, there is need for obtaining complete information on the quality of the water to be used for irrigation.

30. ANONYMOUS. 1954. Spray Irrigation. *Tech de l'Eau* 8:No. 92, 23-28, *Water Poll. Abst.* 28:224 (1490).

Spray irrigation is useful in that it involves less wastage of water than methods previously used, requires no land preparation, leaves more room for the crops, can be used on undulating ground, and can be used in very permeable soils where other methods are useless. The higher expense is largely compensated by considerably lower maintenance costs. Its use in France is discussed.

31. BACHMANN, G. 1954. The Sewage Utilization Plant at Memmingen. *Wasserw.-Wass. Techn.* 4:191. *Water Poll. Abst.* 29:28 (166).

The author describes the sewage works of Memmingen where sewage, after sedimentation for 1.5 hours, is used as artificial rain. The yield of hay on watered land has been increased by 52 percent.

32. FRIES, W. 1955. Agricultural Utilization of Sewage as Artificial Rain. *Der Volkswirt* 9:19. *Water Poll. Abst.* 29:244 (1350).

The author emphasizes the importance of using domestic and industrial waste waters to the greatest extent for supplementing groundwaters. One method of achieving this purpose is to apply them to agricultural land as artificial rain, which has the additional advantages of helping agriculture and reducing pollution of surface waters. Long experience with existing sprinkling systems shows that hygienic risks should not be over-estimated.

33. Grubinger, H. 1953. The Probelm of Agricultural Utilization of Sewage. *Bodenkultur* 7:279-291. *Soils and Fertilizers* 18:64 (327), 1955.

The author discusses the technical features of the purification of sewage and sprinkler irrigation with sewage. Irrigation with 1500-3000 cu.m. per hectare of purified sewage annually supplies 120-240 kg/ha N; 30-60 kg/ha P_2O_5; and 52-104 kg/ha K_2O. Irrigation with such waters and application of the sludge are particularly suited for nitrogen fertilizing, especially of grassland.

34. Henry, C. D., Moldenhauer, R. E., Engelbert, L. E., and Truog, E. 1954. Sewage Effluent Disposal Through Crop Irrigation. *Sewage and Ind. Wastes* 26:123-133.

The utilization of sewage effluent was studied over a 3-year period by means of lysimeter and field irrigation. The purpose of the study was to determine how much effluent could be disposed of through irrigation, the benefits to the crop of both the additional water and fertilizer supplied by the waste waters, and the effect of irrigation with effluent on the chemical content and microbiological population of the percolating waters.

The results are summarized as follows:

1. In the area under study, 40 in. or more of sewage effluent can be applied to a crop of Reed canary grass during the growing season. It is likely that less effluent could be applied to crops that grow over a shorter period, or are not as tolerant to wet soil conditions.

2. The crop and soil are effective in removing virtually all of the nitrogen, phosphorous, and potassium from the percolating waters. When there is high sodium in the effluent, the losses of calcium and magnesium to the percolate are increased. If too much Ca and Mg are lost, and the sodium continues to accumulate in the soil, the physical condition of the soil will be harmed.

3. Crop yields were substantially increased by plant nutrients in the effluent.

4. Drainage waters from the soil did not increase the coliform index of the nearby creek. The chloride and sodium content of the creek waters was increased. The effectiveness of the soil in reducing the coliform numbers of percolating waters was substantiated by analysis of the groundwater. The coliform index (except in one instance) never exceeded 100, in contrast to an index of about 10 million in the effluent applied to the soil.

35. Hunt, Henry J. 1954. Supplemental Irrigation with Treated Sewage. *Sewage and Ind. Wastes* 26:250-260.

The history of sewage irrigation is reviewed. During the latter part of the 19th century, several sewage farms were established in England, Germany, France, and Italy. The first reported use of raw sewage for this purpose in the U. S. was at Cheyenne, Wyoming in 1883. As the art of sewage treatment developed, it was found that the application of the effluent was more desirable. It is stated that "under present conditions, the effluent from a modern treatment plant is safe for application to growing crops of all kinds."

The factors affecting supplemental irrigation are discussed. These are water requirements, area required, best crops, methods of application, increased yields, and time and amount of irrigation. Factors influencing the amount of irrigation are soil type, kind of crop, and local weather conditions. Lengthy periods of soil saturation must be avoided, since it is required that soil air enter the root zone. Climatic data are shown for several U.S. stations.

36. IPPOLITO, G. 1955. Agricultural Utilization of Sewage. *Ingegn. Sanit.* 1:15-20. *PHE Abst.* 35:S:77-78. *Water Poll. Abst.* 29:202 (1107).

The author advocates broad irrigation with emphasis on the utilization of sewage for the growing of crops rather than as a method of sewage disposal. Before installation, studies of crop selection and rotation must be made in order to fully utilize the sewage. Sewage treatment plants will be necessary at most locations to provide acceptable sewage disposal for those periods when crop raising is not practicable. Plain sedimentation is recommended for the sewage prior to its use for irrigation to reduce the quantity of organic matter in the irrigation water; the utilization of the resulting sludge as fertilizer elsewhere is recommended.

37. JANERT, H. 1954. The Suitability of Different Methods of Application for the Utilization of Sewage. *Wasserw.-Wass. Tech.* 4:231. *Water Poll. Abst.* 29:28 (160).

The author recommends subsoil irrigation as the best method for agricultural utilization of sewage. Costs of surface and subsoil irrigation are about the same, while artificial rain costs more than twice as much. The hygienic advantages of subsoil irrigation are discussed in detail.

38. JEPSON, C. 1951. The Availability of Nitrates in Sewage Effluents. *Jour. Inst. Sew. Purif.* (British) 148. Abst: *Sewage and Ind. Wastes* 27:355.

Although oxidized nitrogen is a potential source of oxygen, the latter does not become available for biological life until all the free dissolved oxygen has disappeared. Presence of nitrate in an effluent can delay or prevent the onset of putrescence. Given an adequate retention period during which any dissolved oxygen is exhausted, settled sewage may be improved in quality by the reduction of oxidized nitrogen. To obtain a correct estimate of oxidized nitrogen, analysis should be made as soon as possible after sampling or special precautions taken to retard biological activity.

39. JULEN, G. 1953. Some Aspects of Irrigating Grassland in Humid Regions and the Use of Sewage. *Proc. Sixth Int. Grassland Conf.* 1952, I, 394-396. *Soils and Fertilizers* 18:450 (2303), 1955.

Higher grass production can be obtained by irrigating during periods of drought when insolation is greater than by high rainfall associated with poor light conditions. Sewage waters are useful, though their high N content may depress legumes in leys.

40. MERZ, ROBERT C. 1955. A Survey of Direct Utilization of Waste Waters. *Calif. State Water Poll. Control Bd. Sacramento, Pub. No. 12,* 80 pages.

A comprehensive survey of current practices in the use of waste water by industry, by agriculture, for recreation, and for groundwater recharge. The study permitted the following conclusions with regard to the agricultural use of waste water: (a) Sewage effluent has been shown to be a satisfactory irrigation water, where chemical concentrations permit and where health regulations pertaining to type of crop are met; (b) Sewage effluent has been shown to be an adequate medium for leaching alkali soils, or improvement of barren soils; (c) Reclamation by land irrigation is a means of protecting the quality of surface waters; (d) Irrigation provides secondary treatment and disposal of wastes in an economical manner and may provide the municipality with a substantial monetary return; and (e) An ideal use of oxidized sewage effluent is for irrigation of parks and golf courses and as a supply for decorative lakes. Conclusions pertaining to other uses are also given.

Numerous examples of reuse are cited, and pertinent abstracts from the literature are incuded. The bibliography contains 227 entries.

41. MULLER, W. 1955. Irrigation with Sewage in Australia. *Wass. u. Boden* 7:12. *Water Poll. Abst.* 29:202 (1108).

The author gives an account of the conditions under which sewage is used for irrigation in Australia. Only settled and biologically treated sewage may be used. Surface irrigation is preferred. The amounts vary from 350 to 7500 mm. per year. Land for arable and pasture use and for fruit growing is irrigated.

42. PAULSMEIER, F. 1955. Experiences in the Agricultural Utilization of Sewage. *Desinfekt. u. Gesundheitswes.* 47:118. *Water Poll. Abst.* 29:202 (1109).

From experience with the irrigation fields of Berlin, the author discusses the agricultural and economic advantages of agricultural use of sewage. He gives figures for the amounts of nutrient substances in the sewage of Germany and deals with arguments raised against agricultural utilization.

43. PAULSMEIER, F. 1955. Agricultural Utilization of Sewage as a Municipal Duty. *Kommunalwirtschaft,* No. 8, 406. *Water Poll. Abst.* 29:352 (1931).

The author discusses the economics of agricultural utilization of sewage with special reference to conditions in Hamburg.

44. ROCKWELL, F. L. 1954. Effluent for Irrigation. *Amer. City* 69: No. 9, 92. *Water Poll. Abst.* 28:234 (1559).

Brownsville, Texas has a new plant for sewage treatment consisting of primary sedimentation tanks, percolating filters, and final sedimentation tanks. Sludge is digested and dried on open beds. Owing to the shortage of water for irrigation, farmers have been allowed to divert the effluent being discharged to the Rio Grande to irrigate crops of cotton and corn.

45. SCHWARZ, K. 1955. New Experiences in Agricultural Utilization of Sewage. *Wasserwirtschaft, Stuttgart* 46:55. *Water Poll. Abst.* 29:203 (1110).

The author reviews the papers presented at a meeting of the Deutsche Akademie der Landwirtschaftswissenschaften at Berlin in February 1954. Subjects dealt with include: experiments in Neustrelitz on the use of artificial rain on very light soils; the relations between watering, soil, and plant growth in localities of poor soil and the necessity for adequate additional organic manuring; the effect of artificial rain on the mainly heavy soils of Thuringia; economic problems; subsoil irrigation and its results in Delitzsch; and irrigation fatigue in fields overloaded with sewage.

46. SCHWARZ, K. 1955. Subsoil Irrigation in the Agricultural Utilization of Sewage. *Wasserw.-Wass. Techn.* 5:371-373. *Water Poll. Abst.* 30:25 (148).

Investigations in the experimental irrigation fields at Greifswald, Delitzsch, and Neustrelitz, on subsoil irrigation, are not sufficient for a final judgment of this method of application of sewage. Further experimental irrigation on fields of medium and heavy soils is recommended. Further investigations on hygiene and the technique of construction and operation of plants are required.

47. SISSON, DONALD R. 1955. Some Principles of Agricultural Irrigation. *Proc. 10th Ind. Waste Conf., Purdue Univ.* 89:519-526.

Irrigation is one of the more important practices designed to minimize the "gamble" in modern agriculture. The benefits of irrigation as practiced in the Midwest are noted. The important factors to be considered in designing an agricultural irrigation system are discussed, as well as some of the problems in the use and management of the system. Some of the hazards and problems associated with waste disposal, by agricultural irrigation are pointed out.

48. SKULTE, BERNARD P. 1953. Agricultural Values of Sewage. *Sewage and Ind. Wastes* 25:1297-1303.

Actual experiences for half a century in Europe with skillfully designed and properly managed sewage farming has demonstrated that sanitary sewages and many industrial wastes can be sucessfully used for agricultural, industrial, and other purposes. Studies and practices in more than 100 localities in southern states of this country have shown that land disposal of water recovered from most sewages can be successfully employed to supplement other water supply sources in water-short areas. The sewage as used for irrigation is usually given primary treatment. After that, the processes of natural soil filtration and biochemical stabilization can produce an oxidized and well-treated percolation water. Reclamation programs planned only for groundwater replenishment are usually unsound economic ventures. Therefore, the emphasis should be on the agricultural values in sewage, greatly reducing the immense fertilizer bill and improving soil conditions.

49. SMITH, R. L. and SUBBY, W. 1955. Control of Fertilizing Minerals in Sewage Plant Effluents. *Publ. Wks.* 86: No. 2, 91-92. *Water Poll. Abst.* 29:63 (367).

Minerals in sewage-works effluent can cause excessive algae blooms in lakes due to the fertilizing value of the minerals. Methods suggested for solving the problem include diverting the effluent from the lake, with discharge to a flowing stream; disposal on land by furrow or spray irrigation; or removal of algae and thereby removal of fertilizing minerals. The first method was found to be costly and ineffectual as the minerals had already entered the lake. The second method was also expensive as plants had to be removed before death to prevent return of excess minerals to the soil and, also, because the area of irrigation had to be constantly changed. There was danger of producing high nitrate concentrations in the groundwater in the area. The removal of algae and minerals was found most satisfactory. The algae removed can be used for fertilizer. The lake water was filtered through paper in a metal trough-shaped filter. A description of the filter is given.

50. STONE, RALPH. 1955. Irrigation with Waste Water. *Public Works* 86:97-98, 134-135. *PHE Abst.* 36:S:4.

The author states: "The reuse of sewage and industrial waste waters for irrigation is a means of conserving our available water resources." Not all sewage and industrial wastes in all climates can be safely disposed of by irrigation. In California, 69 localities use waste water for crop irrigation. Beef cattle appear to drink waste water in preference to potable well water. Sewage and industrial waste must be treated regardless of its disposition. Therefore, the cost of treatment should not be charged against the use of water for irrigation. Parks, golf courses, orchards, pastures, cultivated areas, etc., produce more luxuriant crops when irrigated with waste water. Water with a high mineral content is considered unsatisfactory for irrigation. Ponding of waste water from over-irrigation creates nuisance and health hazards and should not be permitted.

51. THACKWELL, H. L. 1955. Sewage and Waste Treatment for Coal Mining Community, Sunnyside, Utah. *Wastes Engr.* 26:352-353. *Water Poll. Abst.* 29:61 (359).

A new sewage-treatment plant has been constructed. It consists of bar screens, aeration tank and grit removal, Imhoff tank, dosing tank, percolating filter, final sedimentation and chlorination tanks, and sludge drying beds. The final effluent is used for irrigation. A flow diagram of the plant is given.

52. WEBSTER, R. A. 1954. Sewage Effluent Disposal Through Crop Irrigation. Discussion. *Sewage and Ind. Wastes* 26:133-135.

The author reviews the history of waste water utilization at Seabrook Farms, Bridgetown, New Jersey. Two distinct advantages are noted: (a) a source of water for crops, and (b) recharge of the groundwater. There has been no evidence of any harmful effects on any potable water (wells) in the immediate vicinity of the spreading area. It has been a happy solution to a waste disposal problem. Before others try the method, the soil should be carefully examined with reference to its absorptive characteristics. The groundwater level should be ascertained to determine the capacity of such a reservoir. Actual tests give the best answers and may save much difficulty later.

53. ZUNKER, F. 1955. Fundamental Points on Agricultural Utilization of Sewage. *Wasserw.-Wass. Tech.* 5:258. *Water Poll. Abst.* 29:352 (1933).

A detailed survey is given of the requirements and advantages of agricultural utilization of sewage and of the operation and economics of different methods.

1956 — 1960

54. BOCKO, J. 1956. The Effect of Sprinkling Irrigation with Sewage on the Productivity of Meadows and Some Biochemical Phenomena in the Soil. *Soils and Fertilizers* 19:2471. *Chem. Abst.* 52:15808 (1958).

On deep, light, alluvial soil, increases in hay yields obtained by irrigation with sewage at rates ranging from 90 to 510 mm/ha were directly proportioned to the amount of sewage applied, and amounted to about 2 quintals/ha for each 100 cu.m. of sewage (100 mm/ha). The highest hay yield of 137 quintals/ha was obtained where sewage was applied at the rate of 510 mm/ha. Irrigation with sewage markedly increased the number of bacteria in the surface soil layer.

55. BOHANAN, LUTHER B. 1958. Irrigation Use of Water. *Jour. Amer. Water Wks. Assn.* 50:310-314.

The author discusses some of the critical aspects of irrigation water use. Inasmuch as irrigation is a consumptive use of water, large amounts of water will be needed to meet future irrigation needs if projected growth rates materialize.

56. DAVIS, IRVING F., JR. 1959. Ground Water Use and Irrigated Land Values. *Proc. Western Farm Economics Assn.,* 32nd Annual Meeting 106-117.

Using hypothetical situations, the author considers the effect of varying rates of pumping from a limited groundwater supply on farmland values. Where competitive pumping is involved, legal controls may be necessary to regulate the rate of pumping. The author suggests cooperation to artificially replenish groundwater supplies as another method for boosting land values.

57. Day, A. D. and Tucker, T. C. 1959. Production of Small Grains Pasture Forage Using Sewage Effluent as a Source of Irrigation Water and Plant Nutrients. *Agronomy Journal* 51:569-572.

Winter pasture forage yields of 11.14 tons per acre were obtained from barley irrigated with sewage effluent with no additional fertilizer. Similarly, wheat and oats production was 263 percent and 249 percent higher, respectively, than for check plots that received only pump water. Barley was more sensitive to the detrimental effects of sewage effluent than were wheat and oats.

58. Day, A. D. and Tucker, T. C. 1960. Hay Production of Small Grains Utilizing City Sewage Effluent. *Agronomy Jour.* 52:238-239.

City sewage effluent can be utilized efficiently to produce hay from small grains in the irrigated areas of the Southwest and possibly elsewhere in the United States and the world where small grains benefit from supplemental irrigation water and fertilizer.

59. Dye, E. O. 1958. Crop Irrigation with Sewage Plant Effluent. *Sewage and Ind. Wastes* 30:825-828.

Irrigation with sewage effluent makes use of water which contains some nutritional value and which is usually wasted. It aids the economy of an area and reduces the pollution loads on a water course, especially a dry stream. With few adaptions, it produces no hazards to operators and others. Numerous facts are now available favoring the use of sewage effluents for crop production. Sound sanitary principles are required in application. The increased yield of farm products is a major inducement.

60. Heukelekian, H. 1957. Utilization of Sewage for Crop Irrigation in Israel. *Sewage and Ind. Wastes* 29:868-874.

Distinction is drawn between the disposal of sewage on land and the utilization of sewage for crop production. Failures and difficulties encountered with the former need not arise when utilization is the main objective. With land disposal systems, the tendency is to apply more sewage to a limited area than can percolate through the soil. Waterlogging of the soil and odors result. When application is geared to the needs of the soil and crop, these problems do not arise. Under proper climatic and soil conditions and with proper control, irrigation with sewage effluents need not create nuisance conditions or health hazards. In certain areas of the world, crop irrigation is an economic necessity for the development of agriculture, and at the same time it can solve the sewage disposal problem.

Sewage effluents are proposed as a resource to augment present water supplies and allow further expansion of irrigated agriculture. Factors affecting the successful utilization of sewage for crop production are discussed. Two alternatives for the treatment of irrigation sewage are suggested:

1. The sewage could be subjected to secondary treatment and thorough disinfection and the effluent used for unrestricted crop irrigation.

2. The sewage could be given minimum treatment and the effluent utilized without disinfection for irrigation of crops not eaten raw by human beings.

Experiments are described which compared sewage irrigation with municipal water supply. Significantly greater yields on sewage-irrigated plots were attributed to regular supply of nutrients throughout growing season instead of just at beginning.

61. Johnson, William E. 1958. Not a Drop Wasted. *Amer. City* 73:111-112 (Feb.).

The city of Ephrata, Washington sells its effluent to be used for irrigation. Hay and corn are the principal crops grown. Presently, 80 acres are being irrigated.

62. Kowalski, J. 1959. Utilization of Sewage for Irrigation. *Nasa Veda* 6:68-72. *Water Poll. Abst.* 38:93 (467).

On the basis of calculations to determine the most economical method of sewage treatment for Bratislava, Czechoslovakia, the author recommends disposal by irrigation.

63. Merz, Robert C. 1956. Report on Continued Study of Waste Water Reclamation and Utilization. *Calif. State Water Poll. Control Bd., Sacramento, Pub. No. 15,* 90 pages.

A continuation of the study reported in Publication No. 12 (1955). Reports on the progress of two principal studies. The first concerned reclamation of liquid, digested sludge in San Diego County for a twofold purpose: enrichment of waste lands and lessening of the pollution of San Diego Bay. The other concerned reclamation of a raw sewage lagoon effluent at Mojave, California, also for a twofold purpose: providing a Marine Air Base with a suitable, economical, irrigation water; and demonstrating that the raw sewage lagoon, when well designed and operated, can be an adequate means of sewage treatment for the small, desert community. Conclusions and recommendations are summarized. A short bibliography and 22 pertinent abstracts are included.

64. Merz, Robert C. 1957. Third Report on the Study of Waste Water Reclamation and Utilization. *Calif. State Water Poll. Control Bd., Sacramento, Pub. No. 18,* 102 pages.

The third and final report prepared on the subject of reclamation and utilization of waste waters. The two previous reports are Publication No. 12, 1955, and Publication No. 15, 1956. In addition to concluding studies previously begun, the report describes a major undertaking in the field of agricultural utilization of waste waters in the Talbert Valley of Orange County, California.

The findings of the overall study were conclusive and they reaffirmed the earlier conviction that waste water reclamation and utilization are both feasible and desirable. Conclusions are summarized for the overall study. Fifty-two abstracts from the literature are included.

65. Merz, Robert C. 1958. Report of the Water Reclamation Forum, Stockton, California. *Water and Sewage Works* 105:306-307.

Summarizes the reports of five speakers at the forum.

Settled sewage from Santa Ana irrigates 2,250 acres growing alfalfa and sugar beets, and on a pre-irrigation basis, lima beans and chili peppers. This effluent is high in dissolved solids, but is considered to be better than the available groundwater. The cost is $5.00 per acre-ft. to the irrigators.

San Bernardino sells effluent for irrigation, but plans to improve the treatment process and use the effluent for recharging the groundwater.

Golden Gate Park uses 0.75 mgd from the San Francisco treatment plant. Contemplated plant improvements will make 5 mgd available for irrigation.

Oceanside will use oxidation ponds for final treatment to prepare its sewage effluent for commercial and irrigation use.

A Marine Corps base in the Imperial Valley pays $55 per acre-ft. for water piped in from 15 miles away. Reclaiming its sewage plant effluent by pond treatment and using it for irrigation and flushing will effect an annual savings of $24,000. Reuse in the desert areas is expected to increase.

66. Prochal, P. 1958. Agricultural Usage of Sewage of the Town of Zory. *Zesz. Nauk. Wyzsej.* No. 5, p. 165-183. *Chem. Abst.* 53:8483.

The nitrogen content of this sewage is 154 mg/1; phosphorous content is 18 mg/1; and potassium content is 52 mg/1. There is only a small amount of toxic sulfides, but a large amount of toxic lipids. If used as a fertilizer this sewage should increase meadow crop yields fivefold, field crops should be doubled, and the yield of fish from ponds should be increased fourfold.

67. Renshaw, Edward F. 1958. Value of an Acre-Foot of Water. *Jour. Amer. Water Wks. Assn.* 50:303-309.

The author states that the demand for various types of water has been the subject of several studies. An attempt is made to summarize information on values of water in such a way as to make comparisons within and between seven water-use categories.

68. Scott, T. M. 1959. Effluent Grows Crops on "Sewer Farm." *Wastes Engr.* 30:486-489.

Bakersfield, California uses semi-arid land in the San Joaquin Valley to dispose of its sewage effluent. The land is city-owned and leased to farmers who produce cotton, feed corn, and other crops not used for human consumption. The farm comprises 2,500 acres. Over 8,000 acre-feet of primary sewage effluent has been used to reclaim marginal alkali land of low value into fertile farm land. This method of disposal also circumvents the problems encountered when plant effluent is discharged into a stream which has extremely low flow in dry periods.

The farm acreage can handle about twice the present effluent dosage of 8,480 acre-feet per year.

Details of the treatment plant operations are given. A portion of the effluent is chlorinated and retained at the plant for watering lawns and as cooling water.

69. Skulte, Bernard P. 1956. Irrigation with Sewage Effluents. *Sewage and Ind. Wastes* 28:36-43.

The primary objective of early sewer farms was simply disposal with the result that often too much sewage was used on too little land. New methods of using sewage for planned irrigation increase its value in water-short areas.

Reviews the history of sewage farming in Europe where it has operated successfully for decades. Any acceptable method of application may be used. Spray irrigation has proved one of the most successful.

Urges more emphasis on pilot plant and research installations to study irrigation with sewage effluents and industrial wastes. Many of the outstanding problems could thus be solved and the most effective methods developed.

70. Stone, Ralph and Merrell, John C., Jr. 1958. Significance of Minerals in Waste-Water. *Sewage and Ind. Wastes* 30:928-936.

Mineral quality is the controlling factor in employing reclaimed wastewater for many purposes. A normal sewage effluent will develop additional mineralization of 100 to 450 ppm. measured as total dissolved solids in one municipal water-use cycle. Mineral pickup greater than 600 ppm. is probably attributable to tidal water or oil field brines. Industrial wastes may contain toxic constituents such as boron or heavy metals.

Treated sewage effluent can provide water of reasonable mineral quality, suitable for irrigation of grasses or other vegetation, industrial water supply, and groundwater recharge.

Analyses of waste water indicate that toxic materials, heavy metals, and other minerals can be suitably controlled within a sewage system.

71. Tonty, Robert L. 1958. Future of Irrigation in the Humid Area. *Jour. Farm Economics* 40:636-652.

The status of irrigation in humid areas is reviewed. An explanation is presented of why irrigation expanded so rapidly in the postwar era. The competitive water uses, including future needs for irrigation, are analyzed.

72. Travis, Paul W. 1960. Organizing a Sewage Effluent Utilization Project. *Pub. Works* 91:119-120.

Southern California's Talbert Water District uses the effluent from the Orange County Sanitary District's primary sedimentation plant for crop irrigation under approval of health officials. Preceding the full-scale installation, irrigation of a model farm of several acres was studied for 3 years to observe effects on local soil and on subsoil percolation.

Strict regulations were adopted in regard to reservoir management, pumping from the treatment plant outfall main, and salt accumulation in the soil. Major points covered in agreements between supplier and user are discussed. The farmer pays $6 per acre-foot for the effluent pumped to his highest land. Some 2,800 acres are irrigated in the system. The farm advisor believes that crops can be doubled with the incidental application of the added nutrients.

73. WADLEIGH, C. H., WILCOX, L. V., and GALLATIN, M. H. 1956. Quality of Irrigation Water. *Jour. Soil and Water Conserv.* 11:31-33.

The quality of irrigation water is determined by the kinds of dissolved salts, the relative proportions of certain ions, and the total concentration. This paper is concerned with evaluation of water quality as affected by naturally occurring solutes.

74. WIERZBICKI, JAN. 1956. Agricultural Utilization of Sewage Waters. *Soils and Fertilizers* 19:2096. *Chem. Abst.* 52:15806 (1958).

Sewage water contains 80 kg/1,000 cu.m. of N, 20 of P_2O_5, and 60 of K_2O. Irrigation with sewage waters increased the yields of hay by 300 to 400 percent, cereals by 20 to 50 percent, and root crops by 100 percent; and it increased the protein content in hay from 6 to 17 percent.

75. WIERZBICKI, JAN. 1957. Augmenting Water Supply Sources Through Agricultural Utilization of Municipal Sewage. *Gaz. Woda i Tech. Sanit.* (Polish) 31:17. Abst: *Sewage and Ind. Wastes* 29:1096.

The author reviews the experience of the town of Bielefeld in augmenting its groundwater resources through the utilization of municipal sewage for surface irrigation. Following the sewage utilization program, the groundwater tables in the area rose, and 620 hectares of formerly nonutilizable land have been converted into meadows, pasture, and plowed land.

76. WILCOX, LLOYD V. 1958. Water Quality from the Standpoint of Irrigation. *Jour. Amer. Water Wks. Assn.* 50:650-654.

The author points out that water quality criteria for crop production differ in many respects from those for domestic or industrial requirements. Salinity is the problem most frequently encountered in the use of city water for irrigation of lawns. The effects of sodium, boron, and bicarbonate concentrations in irrigation water are discussed.

1961 — 1965

77. ANONYMOUS. 1963. Treated Sewage Irrigates Crops. *Engr. News-Record* 171 (Part 2): 45-46 (Oct. 3).

Pennsylvania State University conducts a spray-irrigation program to test the effect of treated domestic sewage on forest plantings and adjacent croplands. The experiments seek to show how plant nutrients in waste water can be conserved and best put to use in a community. The program workers expect to learn how much acreage should be irrigated, best rates of application, and the equipment needed.

Part of the effluent is sprayed on fields planted to rye, wheat, corn, and alfalfa. That diverted to forested areas is sprayed on tree tops from elevated nozzles. The experimenters expect to learn its effect on crops and timber as well as its effect on game and fish.

Initial results look favorable.

78. ANONYMOUS. 1964. Effluent Utilization. *Jour WPCF* 36:1443.

To abate stream pollution and at the same time provide fertilizer nutrients for crops, Pennsylvania State University sprays a portion of its sewage plant effluent on fields to be planted with rye, wheat, corn, and alfalfa. Other uses include spraying the effluent on tops of trees from elevated nozzles and lagooning with seepage to an underground strata. This will help eliminate problems caused by high concentrations of phosphates in the effluent, which previously caused serious stream pollution.

79. BLANEY, H. F. 1962. Utilization of Water and Irrigation in Israel. *Jour. Irr. and Drainage Div.*, Amer. Soc. Civil Engr. 88:IR2, 1, 55. *PHE Abst.* 42:319.

The needs for and potentials of reuse of sewage as irrigation water in Israel is discussed. It is stated that the State of Israel's future and the economic welfare of its agriculture are more dependent on the supply and quality of irrigation water than any other single resource. The total water resources are estimated at 2,000 million cu.m., of which 1,500 million cu.m. will be allocated to irrigation. Return flow from sewage and irrigation is estimated at 165 million cu.m.

80. BROWNING, G. M. 1961. Effective Use of Water in Agricultural Areas. *Jour. Soil and Water Conserv.* 16:111-115.

The author concludes that, on the average, there is enough water; but the crux of the problem of effective water utilization is that it is not always distributed at the right places at the right time. Thus, we must adopt measures and practices that minimize the detrimental and enhance the beneficial effects of water for all segments of society. Topics considered in this paper include watersheds, soil and water conservation, rainfall, supplemental irrigation, drainage, soil moisture, runoff, and land treatment.

81. CHAPMAN, C. J. 1962. Pasture Fertilization with Sewage Effluent Irrigation. *Compost Science* Vol. 3, No. 3, p. 25.

Wisconsin tests show crop yields greatly increased by irrigation with waters carrying effluent from city sewage disposal system.

82. CORMACK, R. M. M. 1964. Irrigation Potential of Sewage Effluents. *Jour. Inst. Sew. Purif.* (British) Part 3, p. 256-257.

Scarcity of water in Southern Africa makes the use of sewage effluent for irrigation attractive and worthy of consideration. Whether reclaimed water is used for one purpose or another matters little in the final analysis. Every gallon of reclaimed water represents a saving from other sources of supply.

The use of reclaimed sewage effluent for agricultural and horticultural purposes represents not only sound water economy but also good fertilizer economy. It is estimated that the fertilizer value in sewage effluent from the Aisleby Works at Bulawayo is about 7 cents per 1,000 gallons.

83. DAY, A. D., TUCKER, T. C., and VAVICH, M. G. 1962. Effect of City Sewage Effluent on the Yield and Quality of Grain from Barley, Oats, and Wheat. *Agronomy Jour.* 54:133-135.

Grain yields of 3,032; 2,346; and 2,201 pounds per acre were obtained from barley, oats, and wheat, respectively. Small grains utilized the nitrogen in sewage effluent as efficiently as they used the nitrogen in commercial fertilizer to produce high protein grain. Sewage effluent had no effect on the digestible laboratory nutrients content and bushel weight of barley, oats, and wheat.

84. DAY, A. D., TUCKER, T. C., and VAVICH, M. G. 1962. City Sewage for Irrigation and Plant Nutrients. *Crops and Soils,* Vol. 14, No. 8.

Municipal sewage wastes may be a blessing in disguise for arid regions of the world, particularly where irrigation water is in short supply. Modern sewage-processing plants produce a clear effluent that is safe for certain agricultural use. When properly treated, this material could add considerably to our total water supply.

85. DAY, A. D., TUCKER, T. C., and VAVICH, M. G. 1962. Sewage Effluent. *Progressive Agriculture in Arizona,* Vol. XIV, No. 5.

In the arid regions throughout the world, the normal rainfall is not sufficient to provide maximum production from agricultural crops. Supplemental irrigation water is often unavailable or too expensive for agricultural use. Many geographical areas that would benefit from supplemental irrigation water are faced with the problem of municipal sewage disposal.

City sewage effluents can be utilized efficiently as a source of irrigation water and plant nutrients in the production of small grains forage and grain.

86. DAY, A. D., DICKSON, A. D., and TUCKER, T. C. 1963. Effects of City Sewage Effluent on Grain Yield and Grain Malt Quality of Fall-Sown, Irrigated Barley. *Agronomy Jour.* 55:317-318.

In general, the application of sewage effluent to barley resulted in an increase in grain yield, percentage of nitrogen, and malt diastatic power; but kernel weight, kernel size, and malt extract percentage were decreased. Although sewage effluent produced high yields of barley grain, it tended to cause a lower grain and malt quality.

87. Dye, E. O. 1961. Plant Effluent Sold for Irrigation Water. *Wastes Eng.* 32:636.

Operational expenditures are defrayed by 40 percent through sale of the effluent, digested sludge, and digester gas from the activated sludge plant at Tucson, Arizona. Also, a portion of the water applied for irrigation serves to recharge groundwater, thus, replenishing to some extent the principal water resource in this arid area.

88. Dziezyc, J. and Trybala, M. 1963. The Effect of Irrigation with Town Sewage on Variously Fertilized Mangel-Wurzel and Sunflower Grown for Fodder. *Zesz. Nauk. Wyz. Szkol. rol. Wroclaw Melior* 8:43-52. *Soils and Fertilizers* 27:327 (2375), 1964.

Application of 300-600 mm sewage water, especially when combined with mineral NPK, increased size of foliage and root diameter in mangold. Growth of sunflower was increased by NPK and depressed by PK.

89. Gray, J. Frank. 1965. Irrigation Processes Using Reclaimed Water or Effluent Described. *West Texas Today* 45: (Jan.) 18-19, 23.

Irrigation with sewage effluent at Lubbock, Texas dates back to the early 1930's. Presently, approximately 2,000 acres are irrigated. The successful operation requires a reservoir storage capacity for about 30 days' output of effluent. The primary difference between irrigation with effluent and general irrigation practice is the requirement of taking all effluent produced.

The chief advantages of irrigation with sewage effluent are regularity of water supply, some fertility value gained, and decreased stream pollution. Some of the disadvantages are odor nuisance, problems created by requirement to take water at all times, more difficulty in keeping farm labor, and over-irrigation which may damage young plants. Data on crops are given.

90. Harvey, Clark and Cantrell, Ronald. 1965. Use of Sewage Effluent for Production of Agricultural Crops. *Texas Water Development Board, Austin, Report 9,* December 1965.

The report summarizes the results of a 1965 Texas survey on agricultural use of sewage effluent. Discussed are the suitability and cost of effluent for crop production as well as crops and acreage irrigated.

The authors state that "crop irrigation with effluent can contribute to the economy of the area and solve satisfactorily the sewage disposal problem."

91. Hershkovitz, S. Z. and Feinmesser, A. 1962. Sewage Reclaimed for Irrigation in Israel Farm Oxidation Ponds. *Wastes Eng.* 33:405.

The authors report on the operation of 36 oxidation ponds in Israel, serving as secondary treatment facilities for sewage from a total population of approximately 90,000. The quality of the effluent is judged to be suitable for the planned irrigation reuse.

92. Highsmith, Richard M., Jr. 1965. Irrigated Lands of the World. *Geographical Review* 55:382-389.

A comprehensive review of the areas of the world where irrigation agriculture is practiced. Data were collected from several sources, and total irrigated acres for each country are presented in tabular form. A world map is included showing the geographical location of irrigated areas.

The impact of irrigation on agriculture is realized when the total irrigated acres are reviewed. In 1961, approximately 37.7 million acres were irrigated in the United States. World totals were estimated to be something over 431 million acres.

93. KUTERA, J. 1963. Possibilities of Increasing the Fertility of Light Soils by Irrigation with Sewage. *Zesz. Probl. Postep. Nauk. rol.* 40B: 239-260. *Soils and Fertilizers* 27:69 (465), 1964.

Due to the high availability of N, P, and K in sewage, its application in irrigation does not result in salt accumulation. It supplies considerable amounts of organic matter to the soil. In irrigating grassland with sewage, 1 cu.m./ha yielded up to 4.5 kg. of high protein content hay.

94. PRAT, S. and SLADECEK, V. 1964. An Inexpensive Bioassay Aimed at the Agricultural Disposal of Waste Waters. Hydrobiologia 23:246-252. *PHE Abst.* 44:309.

A method of bioassay is described for detecting the toxicity of waste waters to germinating plant seeds and evaluating the suitability of the waters for irrigational use. Seeds of the mustard, *Sinapis Alba,* are placed in petri dishes on Silon or nylon textile fabric and irrigated with the water under investigation. They are kept in the dark at 16-20°C and observed daily for 3 days. The numbers of germinating seeds, the lengths of the rootlets, and the ratios of root length to hypocotyl length are recorded as indices of water quality. Stimulation of growth of rootlets as well as toxicity of the water can be detected by comparison with controls.

95. REUTLINGER, S., and SEAGRAVES, J. A. 1962. A Method of Appraising Irrigation Returns. *Jour. Farm Economics* 44:837-850.

A method of computing the increased crop yield from a series of irrigation experiments is described. The method is explained with the aid of an example in which an expected yield increase and synthetic cost data are used to evaluate the profitability of investing in irrigation systems for tobacco in the Coastal Plain of North Carolina.

96. TRYBALA, M. 1963. The Effect of Irrigation with Town Sewage on the Production of Variously Fertilized Winter Rape. *Zesz. Nauk. Wyz. Szkol. rol. Wroclaw Melior* 8:29-42. *Soils and Fertilizers* 27:327 (2376), 1964.

Application of 150-350 mm sewage water promoted the growth of rape on unfertilized plots and on plots given minerals P and K.

97. WATSON, JOHN L. A. 1963. Oxidation Ponds and Use of Effluent in Israel. *Effl. and Water Treat. Jour.* 3:150-153. *PHE Abst.* 43:272.

Oxidation ponds are used as aids in reclaiming sewage effluents. They provide economic and safe treatment of sewage for an effluent suitable for reuse. Principal reuse to date has been for irrigation; but groundwater recharge, makeup water for fish-breeding ponds, and industrial reuse are contemplated.

98. WELLS, W. N. 1961. Irrigation as a Sewage Reuse Application. *Public Works* 92:116-118.

Advantages and limitations in the use of sewage for irrigation at San Antonio, Texas, are reviewed. Disposal by irrigation has avoided the need for a high degree of treatment and has given farmers a dependable supply of irrigation water. Data are shown concerning the chemical content of the water and the types of crops grown. Currently, 16 mgd (approximately one-fourth of the plant effluent) are used to irrigate 4,000 acres for growing cotton, castor beans, feed grains, and forage crops.

The literature on health hazards in sewage irrigation was reviewed as supporting evidence that the use of sewage effluents for growing such crops is not hazardous.

99. WELLS, W. N. 1963. Sewage Plant Effluent for Irrigation. *Compost Science* Vol. 4, No. 1, p. 19.

Farmers beat the drought by using effluent from the San Antonio Treatment Plant. A 3-mile long open canal carries the effluent to Mitchell Lake which acts as an 850-acre oxidation lagoon. About 4,000 acres of farm and pasture land are irrigated from the canal and from the lake.

2

Agricultural Value of Sewage Sludge

Soil scientists have long recognized the value of the small organic fraction in soils. Its favorable influence on physical and chemical properties of soils is far greater in proportion to the very small quantities present. The organic matter content of most soils ranges from 1 to 5 percent. Nevertheless, it commonly accounts for a large part of the cation exchange capacity of soils, and more than any other single factor, it is responsible for the stability of soil aggregates so essential to good soil structure and favorable physical soil properties.

Organic materials were the first fertilizers used by farmers. They were mainly plant and animal residues and were used for their nitrogen-supplying value. More recently, the lower cost and greater availability of plant nutrients in mineral fertilizers have led to the replacement of most organics as fertilizers. Organic materials such as farm manure, compost, peat, and sewage sludge continue to be used, however, to improve soil physical conditions. These are commonly referred to as soil amendments rather than fertilizers because of their relatively low content of plant nutrients. In addition to the major essential nutrients, sewage sludges contain appreciable quantities of the minor nutritional elements such as copper, boron, manganese, molybdenum, and zinc. In many cases, the amendments represent utilization of materials that otherwise would be wasted.

Farmers are continually encouraged to add organic material to cropped land. Winter crops are often planted in the fall and then plowed under in the early spring. Crop residues also are allowed to remain in the soil where decomposition contributes to the organic matter content of the soil. Abstracts of reports included in this bibliography clearly indicate that sewage sludge is a valuable soil amendment for the addition of organic matter to soils.

Sewage treatment plants are designed to separate the suspended solids and many soluble constituents from domestic sewage and industrial waste waters. Sewage sludge includes all of the solid and precipitated material separated from the sewage. The clarified effluent or waste water presents much less of a disposal problem than the sludge, since it usually can be released to natural water-courses or applied to any number of suitable reuse situations.

The value of sewage sludge for soil improvement depends on the processes used in the sewage treatment plant. Digested sludge comes from treatment plants in which the solids have been settled out and then digested anaerobically. Typically, the liquid sludge is pumped from the bottom of the digester and allowed to air-dry on sand filter beds. Much of the soluble plant nutrients drain away and are lost in the drying process, leaving a dried sludge that is low in fertilizer value. This type of sludge is seldom sold as a soil amendment.

Activated sludge results from aerobic treatment in which large quantities of air are bubbled through the sewage mixture. The sludge is separated from the liquid phase by settling. The excess sludge that is processed for sale is commonly heat-dried to a moisture content of 5 to 10 percent. The nutrient content of activated sludge is usually higher than that produced by other treatment schemes. The nitrogen content may be 4 to 6 percent, and its phosphorus content normally is 3 or 4 percent. Sludge analyses in several reports abstracted in this bibliography substantiate these figures.

Milwaukee, Wisconsin and Grand Rapids, Michigan have successfully marketed activated sludge from their treatment plants. Sizable revenues from these sales have partially offset the operating costs of the facilities. Many cities reported using their sludge on parks, golf courses, sewage plant grounds, and other municipally owned properties. Others give away the dried sludge for use on lawns or flower gardens.

Sanitary precautions must be taken when digested sludge is used. Pathogenic organisms may survive the treatment process. It is not advisable to use digested sludge on root crops or any vegetable crop that can be eaten raw. Incorporation into the soil well ahead (at least 3 months) of planting time leads to destruction of pathogenic organisms. Nuisance odors from digested sludges can be overcome by immediate incorporation into the soil. Activated sludges present no odor problems, and microorganisms are killed in the heat treatment.

The conclusion drawn from the literature surveyed is that sewage sludges can be a valuable soil amendment when applied to increase the organic matter content and to improve the chemical and physical properties of soils.

Abstracts

Prior to 1951

100. ANONYMOUS. 1937. Report of the Committee on Sewage Disposal, APHA: The Utilization of Sewage Sludge as Fertilizer. *Sewage Wks. Jour.* 9:861-912.

A comprehensive report resulting from a survey of sludge disposal practices in the United States and Canada. Data were furnished by State sanitary engineers, sewage works operators, and municipal officials.

Discussed in connection with use of sludge as fertilizer are soil fertilization, fertilizer value, use in mixed fertilizers, tonnage of sludge available, types of sludge, and comparisons of sludge from different treatment processes.

Results of sludge utilization on many different crops are presented, and general conclusions based on the results of the survey are given.

A bibliography of 89 entries accompanies the report.

101. DAMOOSE, N. 1941. Liquid Sludge–The Vitamin B Fertilizer. *Sewage Wks. Engr.* 12:308-312.

The sale of liquid sludge has been promoted at Battle Creek, Michigan. After successful trials on the plant grounds, a truck was fitted with a 600-gallon tank for delivery of liquid digested sludge to the public. Use of this material on lawns produced "astounding" results. Odor and appearance nuisances were overcome by wetting down with sprinklers following application.

In addition to the plant food value, the author believes Vitamin B plays an important role and discusses this in some detail.

102. DETURK, E. E. 1935. Adaptability of Sewage Sludge as a Fertilizer. *Sewage Wks. Jour.* 7:597-610.

A significant historical review of sewage utilization is made. Comparisons of chemical composition and fertilizer value are made between sludge produced by the activated sludge process and digested or Imhoff sludge. Digested sludge is also compared to farm manure. Methods of sludge utilization are discussed.

Future development of sludge-processing methods may well result in the production of sludge with increased fertilizer value. Even though sludge may be low in fertilizer value, its organic content should not be overlooked as a soil-conditioning agent.

103. HARPER, HORACE J. 1931. Sewage Sludge as a Fertilizer. *Sewage Wks. Jour.* 3:683-687.

Fertilizing value of sewage sludge depends upon its source and the sewage treatment process. The nitrogen content may be quite different for sludges obtained from Imhoff tank and activated sludge processes. Activated sludge may contain 5 to 6 percent total nitrogen, with total phosphoric acid content of approximately 3 percent. Sludge from Imhoff tanks seldom contains more than 2.5 percent nitrogen and 2 percent phosphoric acid.

Cites the city of Milwaukee's experience with "Milorganite" produced from activated sludge and several experiments concerned with fertilizer value of sludge. Liquid sludge has considerably more fertilizer value than dried sludge since much of the nutrient content drains away in the drying process.

104. Maloy, Thomas P. 1931. Use of Sludge as Fertilizer. *Sewage Wks. Jour.* 3:485-487.

Sludge does not have the high fertilizing value of commercial fertilizers. Experiments indicated that it is very effective in improving the physical condition of the soil:

"Where the ground was hard and compact before, it is now soft and resilient. It has a certain amount of spring to it."

"The whole texture of the soil was improved and made more pliable."

105. Mitchell, George A. 1931. Sludge Disposal at a Sewage Irrigation Farm. *Engr. News-Record* 107:57.

The author describes a method of disposing of sludge-bearing sewage as practiced at Vineland, New Jersey. The sludge is pumped onto a field prepared with deep furrows. Immediately upon drying, the sludge is plowed under, and the field prepared to receive another sludge treatment. Once the sludge is plowed under, odor and insect nuisances are eliminated. The surface soil proved to be an excellent purifier.

106. Muller, J. F. 1929. The Value of Raw Sewage Sludge as Fertilizer. *Soil Sci.* 28:423-432.

Several samples of dried fresh sewage sludge were analyzed, and pot experiments carried out to determine the fertilizer value of such material. The analyses showed considerable potential plant food is present.

The carbon-nitrogen ratio was narrowed to below eight by the addition of available nitrogen, markedly increasing the fertilizer value of the sludge. A phosphate supplement appears to be necessary for good plant growth; and a potash supplement, in small quantities, seems desirable.

The dried sludge alone, with no mineral supplements, when applied to turf grown on sand gave a good stand of grass and prevented its dying off.

Dried fresh sludge applied to a sandy soil materially increased its water-holding capacity, a most desirable result on soils of this type.

Although the experiments reported did not indicate a need for using lime with the sludge, lime almost certainly would be required after several years continuous sludge application.

107. Pearse, Langdon, Niles, A. H., et al. 1946. Utilization of Sewage Sludge as Fertilizer. *Federation of Sewage Works Associations, Manual of Practice No. 2,* 120 pages.

The major topics in the manual are: Fertilizer Requirements of Soils; Fertilizer Characteristics of Sewage Sludge; Effects of Sewage Treatment Practices on Fertilizing Elements in Sludge; Processing Sludge for Use as Fertilizer; Application of Sludge as Fertilizer; Hygienic Aspects of Sludge Utilization as Fertilizer; Prices, Marketing, and Economic Considerations. A closing chapter includes conclusions and recommendations relative to sludge utilization. The bibliography contains 251 entries.

108. Reinhold, F. 1948. New Viewpoints on the Agricultural Utilization of Sewage. *Gesundheits Ing.* 69:296-302. *PHE Abst.* 31:S:45.

Studies were made to determine the relative fertilizing value of settled and biologically treated sewage. It was found that treatment improved the availability of nutrient materials other than nitrogen, and it also increased the formation of humus in the soil.

Spray irrigation allows bacteria to be carried by spray and air movement for distances of 800 meters. They are soon killed by sunlight. The eggs of worms in digested sludge were not viable.

Raw sewage should not be used for irrigation of any kind, and only biologically treated sewage should be used for irrigating vegetables.

109. Rudolfs, Willem. 1928. Sewage Sludge as Fertilizer. *Soil Sci.* 26:455-458.

The nitrogen content of sewage sludge varies with the type of treatment. Aerobically and anaerobically treated sewage sludges contain about 5 and 2.25 percent nitrogen, respectively. Only one sewage treatment plant markets its sludge on a large scale; at a number of places the sewage sludge is given away or sold for a small nominal sum. An estimated 150,000 to 200,000 tons of nitrogen are lost annually. Analysis of sludges from a number of sewage plants indicates that 8,000 to 10,000 tons nitrogen per year could be saved.

110. Rudolfs, Willem, and Cleary, E. J. 1933. Sludge Disposal and Future Trends. *Sewage Wks. Jour.* 5:409-428.

Present methods of sludge handling and disposal are discussed. The need for further development is stressed. Sludge as a fertilizer is discussed from the standpoint of fertilizing value, preparation of fertilizer, and economic and hygienic considerations. Fertilizer production may be profitable only for the large plants. Small plants usually must dispose of sludge material locally as a market develops. Dewatering and incineration offer promise as a means of ultimate disposal.

111. Rudolfs, Willem. 1937. Salvage from Sewage? *Engr. News-Record* 119:1055-1057.

Sewage researchers are urged to change their attitude toward disposal and emphasize the possibilities of by-product recovery and utilization. Present as well as possible future uses of sewage by-products are pointed out.

The agricultural value of returning sewage by-products to the land should not be overlooked. It is stressed that we should change our thinking from destruction of waste to conservation and recovery of useful by-products.

112. SCHRINER, PHILLIP J. 1942. Disposal of Liquid Sludge at Kankakee, Illinois. *Sewage Wks. Jour.* 14:876-878.

Cost figures show that liquid sludge disposal by tank truck delivery constitutes a considerable saving over operation and maintenance of sludge drying beds. It also eliminates the severe operating difficulties of sludge drying beds in the winter months. The use of liquid sludge to fertilize lawns will be promoted, and the practice should show a considerable profit to the city over past experience with sludge drying beds.

113. SKINNER, JOHN F. 1932. Sewage Sludge as Fertilizer. *Sewage Wks. Jour.* 4:279-282.

Sludge from four Imhoff tanks at Rochester, New York is utilized as fertilizer for gardens, shrubs, lawns, and local farm crops. Details of the operation are described, and sales data are shown.

Liquid sludge has much greater nutrient value than dried sludge. Consideration is given to dispensing liquid sludge, thus eliminating cost of constructing and operating drying beds.

114. TATLOCK, M. W. 1932. The Economic Preparation and Sale of Digested Sludge as Commercial Fertilizer. *Sewage Wks. Jour.* 4:519-524.

The author describes in detail the operation of the Dayton, Ohio sewage treatment plant. Cost of operation and income from sales are given. Results show promise. Sludge can be successfully marketed.

115. WIERZBICKI, JAN. 1949. The Need for Pretreatment of Sewage Utilized for Agricultural Purposes. *Gaz. Woda i Tech. Sanit.* (Polish) 23:162. Abst: *Sewage Wks. Jour.* 21:110.

The agricultural use of sewage results in a high degree of treatment, along with the advantages of fertilization and enrichment of soil with humus. Reasons for preferring clarified sewage effluent for irrigation are listed and discussed. Two disadvantages resulting from pretreatment are removal of fertilizer materials and increase in cost of operation. If the sludge is recovered and used as a fertilizer, more of the fertilizing value will be utilized.

1951 — 1955

116. ANDERSON, MYRON S. 1955. Sewage Sludge for Soil Improvement. *U.S.D.A. Circular No. 972*, 27 pages. *PHE Abst.* 36:S:81.

Chemical compositions of sludges variously prepared in different parts of the United States are reported. Only 18 to 25 percent of the nitrogen present in digested sludges is normally nitrified during a 16-week period. Activated sludges show nitrification values of 50 to 60 percent for a similar period. The bibliography has 41 entries.

117. Hayob, Henry. 1954. Disposal of Wet Digested Sludge at Marshall, Missouri. *Sewage and Ind. Wastes* 26:93-95.

Sludge drying beds were eliminated, and liquid sludge is now hauled by tank truck to be spread directly onto farming land. No mention is made of crops grown, soil type, or crop yields. Several problems were solved with this new type of disposal.

118. Kuhlewind, C. 1954. The Necessity for Utilization of Sewage. *Kommunalwirtschaft,* 1953/54, p. 376. *Water Poll. Abst.* 29:353 (1934).

The author deals with the fertilizing value of sewage, giving figures for nutrient matter, water, and humus contents. He dicusses the advantages of agricultural utilization.

119. Thomson, James F. and Morgan, James M., Jr. 1955. Conservation Potential of Sewage Sludge. *Water and Sewage Wks.* 102:532-535. *PHE Abst.* 36:S:7.

Sewage sludge has been used with varying degrees of success to replace fertility of soils. Sludge contains differing amounts of lime, humus, nitrogen, phosphorus, and potash. Recommended applications are 10 to 60 cu. yd. per acre for flowers, vegetables, and grass and 10 tons of wet sludge per acre for orchards. Dewatering has been accomplished by pressing (in England), vacuum filtration (mainly in United States), and centrifuging (in Europe). Sludge processing cost varies from $5.14 to $37.53 per ton, and sale price (1953) ranged from $13.95 to $20.00 per ton.

Average sludge production for the United States is estimated at one million tons per year. Based on analyses from several cities, this would yield 32 thousand tons of nitrogen, 23 thousand tons of phosphate, and 3 thousand tons of potash. There is usually a wide margin between the plant nutrients removed from soil and that which is put back. If all sludge produced in 1949 and 1950 had been used as fertilizer, it probably would have increased production only about 0.5 percent. In spite of this relatively small yield, nothing should be overlooked to increase our agricultural potential.

120. Van Kleeck, Leroy W. 1954. Fertilizer Value in Waste Disposal Methods. *Amer. Jour. Pub. Health* 44:349. Abst: *Sewage and Ind. Wastes* 26:1509.

Dried or partially dewatered sewage sludge makes an excellent soil conditioner and a good, though incomplete, fertilizer. Heat-dried raw activated sludge is the best sludge product, both chemically and hygienically, although some odor may be encountered in its use.

The reasons why more sludge is not used are discussed, as are the advantages and disadvantages of broad irrigation and sewage farming. Garbage composting, both alone and in connection with sewage sludge, is receiving more attention although current practice leaves much to be desired.

1956 — 1960

121. ANONYMOUS. 1958. Sewage Sludge as Soil Conditioner. *Water and Sewage Wks.* 105:484-489. *PHE Abst.* 39:S:46.

Reprinted with permission of Managing Editor, *Organic Gardening and Farming Magazine*. The results of a national survey are presented. Reports the increased sale and demand for sewage sludge to be applied to soil in recent years. Many examples and case histories are cited. Sludge analyses, sales trends, prices, etc., are tabulated for a large number of cities where sludge is sold.

Sludge is recommended for lawns, parks, and flower gardens. It deepens the color of grass and stimulates a luxurious growth that is noticeable for longer than one season. It should be applied late in March and again in September, if desired. It provides needed humus as well as a moderate amount of nitrogen to flower garden soils.

122. ANDERSON, MYRON S. 1956. Comparative Analyses of Sewage Sludges. *Sewage and Ind. Wastes* 28:132-135.

Additional study is needed to understand better the value of sewage sludge for agricultural use. The following topics are indicative of the need for research on the subject.

1. To what extent is the phosphorus in sewage sludges available to plant life?
2. Do the specific feeding powers of various plants differ with respect to their utilization of phosphorus in sewage sludges?
3. What chemical characteristics of sludges most effectively influence the rate of nitrification?
4. Biology of the trickling filter.
5. How is the high nitrogen content developed in activated sludges?

123. ANDERSON, MYRON S. 1959. Fertilizing Characteristics of Sewage Sludge. *Sewage and Ind. Wastes* 31:678-682.

The chemical composition and fertilizer value of sewage sludge depend in part on the method of treatment from which the sludge is obtained. Undigested sludge from secondary treatment has the greatest fertilizer value. Digested sludge from primary treatment has a lower fertilizer value but may be beneficial as a soil conditioner or mulch.

The nitrogen content of digested sludge is appreciably lower. Heat treatment is recommended for sanitary purposes before sludge is sold as a fertilizer.

It is important that prospective users be told what to expect from sludge applied to soil. The plant responses will vary with type of soil, kind of plants grown, and climatic conditions.

124. Delano, E. Huntley. 1957. Sale of "RAPIDGRO" Gives Grand Rapids $150,000 Revenue from Dried Sludge. *Wastes Engr.* 28:30-31. *PHE Abst.* 37:S:88.

The city of Grand Rapids has produced an organic soil builder from its sewage treatment plant since 1932. In the past 14 years, its dried sludge sales have totaled $150,975 against operating costs of $87,771. Analyses of the sludge are given. The cost and other manufacturing aspects of "RAPIDGRO" production are discussed in detail.

125. Fleming, Julian R. 1959. Sludge Utilization and Disposal. *Sewage and Ind. Wastes* 31:1342-1346.

Presents a resume of general methods of sludge disposal and summarizes methods used in 28 towns in Alabama, Arkansas, Florida, Kentucky, South Carolina, and Tennessee. Soil conditioning and fertilizer value of digested sludge are discussed, as are problems associated with the agricultural use of sludge.

126. Leaver, Robert E. 1956. Sludge Disposal Practices in the Pacific Northwest. *Sewage and Ind. Wastes* 28:323-328.

Summarizes the sludge disposal practices at several communities in the Pacific Northwest, principally the State of Washington. Four communities are cited as typifying current practice in the disposal of liquid sludge. Some of it is sold, and some is free to private haulers. Other examples are cited in which communities dispose of air-dried digested sludge and filter-dried sludge. Income from sales is given. Fertilizing ingredients are compared in tabular form for various types of sludge, manures, and other organic materials. The Washington State Department of Health, "General Guide for the Utilization and Disposal of Sewage Sludge," is presented as an appendix to the report.

127. Merz, Robert C. 1959. Utilization of Liquid Sludge. *Water and Sewage Wks.* 106:489-493.

A method for reducing the cost of treatment plant operation plus reclamation of waste land is presented. The city of San Diego has found land disposal a satisfactory and practical method of utilizing the liquid digested sludge produced at its sewage treatment plant. Sludge-drying facilities have been shut down, and all sludge is now utilized for soil improvement. The value of organic matter in the soil for maintaining and storing moisture is well known.

The San Diego liquid sludge disposal operation has shown that (a) waste land can be reclaimed for agriculture with liquid sludge of reasonable solids content at less cost than with dried sludge; (b) sludge loadings as high as 100 tons dry solids per acre can be applied without impairing crop growth; (c) sludge loadings as low as 25 tons dry solids per acre will produce crop growth comparable to that achieved by the use of commercial fertilizer at conventional application rates; (d) an initial sludging with 50 tons dry solids per acre will grow a second superior crop due to residual fertilization not used up by the first; and (e) it is possible to avoid serious sludge handling or nuisance problems.

128. OLDS, JEROME. 1960. How Cities Distribute Sludge as a Soil Conditioner. *Compost Science* Vol. 1, No. 3, p. 26-30.

This report describes the experiences of cities which have been marketing and distributing sludge for soil conditioning purposes and also offers suggestions to improve distribution of these organic wastes.

129. VAN KLEECK, LEROY W. 1958. Do's and Don't's of Using Sludge for Soil Conditioning and Fertilizing. *Wastes Engr.* 29:256-257, 274. *PHE Abst.* 38:S:89.

Various methods of sludge disposal are discussed with emphasis on use as a soil conditioner. The characteristics of both raw and various forms of digested sludge which affect the soil and crops are pointed out. As a guide to the attitude of public health authorities on the use of sludge on soils, the author quotes the policy of the Connecticut State Department of Health.

1961 — 1965

130. EBERHARDT, H. and ERMER, H. 1962. Utilization and Disposal of Sewage Sludge. *Städtehygiene* 13:175-179. *Water Poll. Abst.* 37:92 (458).

The authors discuss the various methods of sewage sludge utilization or disposal and the conditions under which each can be applied. Methods are described for the agricultural use of wet or dry sludge, for drying and composting, and for disposal on land or at sea. Methods for incinerating sludge and for producing gas are also discussed.

131. GLATHE, H. and MAKAWI, A. A. M. 1963. The Effect of Sewage Sludge on Soils and Micro-Organisms. *Z. Pflernahr. Düng* 101:109-121. *Soils and Fert.* 26:273 (1983) 1963.

In pot experiments with sewage sludge applied to loam and sandy soil, fresh sludge had a superior effect in increasing total counts of micro-organisms and cellulose decomposers. Though there was little difference in the effect of autoclaved and ethylene-oxide-sterilized sludge in increasing microbial populations, the former material had the greatest effect in promoting azotobacter. Application of fresh, sterilized, and autoclaved sewage sludge (in this decreasing order of efficiency) increased CO_2 production in soil and promoted the production of NO_3 and NH_4. Fresh sewage contained large numbers of coliform bacteria which rapidly increased in soil for eight days after application and persisted even after thirty days.

132. HUSEMANN, C. and PANNIER, D. 1962. Effect of Different Putrefying Waste-Water Sludge Applications on the Water-Storage Capacity and Yield of a Sandy Soil. *Z. Kulturtech* 3:193-204. *Soils and Fertilizers* 27:327 (2374) 1964.

Applications of sewage sludge markedly increased the water-holding capacity of the soil and increased yields of lettuce. Effectiveness of the sludge depended on its source, composition, consistency, and preliminary treatment.

133. VLAMIS, J. and WILLIAMS, D. E. 1961. Test of Sewage Sludge for Fertility and Toxicity in Soils. *Compost Science* Vol. 2, No. 1, p. 26-30.

California researchers report on studies comparing the growth of plants receiving applications of sludge and chemical fertilizers. Both fertility and toxicity are considered.

3

Land Disposal of Liquid Wastes — — Pollution Abatement and Effects on Soil Properties

For a long time, soil was considered to be the "universal" disposal medium; more recently, it has been recognized that certain persistent materials resist degradation and appear as pollutants in ground- and seepage-waters. Nevertheless, soil remains as one of the few means for the satisfactory tertiary treatment for domestic wastes. In addition, soil has been proved as an economical and effective means of treatment and disposal for such industrial wastes as those from vegetable and fruit canneries, dairy- and meat-processing plants, and paper and pulp mills.

The methods of application vary widely and are governed by the type and quantity of waste, soil type, land form, and soil permeability. Spray applications are popular for industrial waste disposal since little land preparation is required and the system is flexible and easily managed.

Whether disposal is to cultivated row crops, forage crops, grassland, or forested areas matters little as far as treatment and ultimate disposal are concerned. Waste water applied to land infiltrates the soil, is "purified," and much of it ultimately joins the groundwater reserve from which it can be withdrawn for other uses. Groundwater recharge is the primary objective of many land disposal systems.

Not to be overlooked is the objective of pollution control and prevention in surface waters. Most waste materials create serious pollution and nuisance problems when discharged directly to surface streams. Their disposal to land areas greatly reduces those problems and supplements the underground water supply. The importance of land disposal as a surface water pollution control measure cannot be over-emphasized.

Chemical and physical soil properties are affected by the addition of organic wastes. The research reports abstracted in this bibliography discuss many of these effects such as: (1) increased biological activity, (2) cation exchange, (3) changes in salinity, (4) reduced soil permeability, and (5) increased organic matter content.

As with other irrigation systems, efficient land disposal operations require good management practices. Failure and/or decreased efficiency seem to be due most often to overloading. Adequate area must be provided to accommodate the wastes without overloading. For successful operation, irrigation must be intermittent, allowing drainage and aeration of the soil between treatments. Cultivation is recommended after the drying cycle to break up the organic layer on the surface and increase infiltration.

Land disposal systems are worthy of consideration in those areas where suitable and sufficient acreage is available. The literature reviewed shows such disposal to be an effective, efficient, and economical operation. The evidence presented indicates conclusively that the use of soil for waste treatment has a definite place in pollution control and waste water reclamation.

Abstracts

Prior to 1951

134. Allison, L. E. 1947. Effect of Microorganisms on Permeability of Soil Under Prolonged Submergence. *Soil Sci.* 63:439-450.

The permeability of continuously submerged soils usually decreases slightly at first and then increases appreciably as the entrapped air is removed by solution in the percolate. Eventually the soil virtually seals up.

Sterile permeability tests to determine the cause of decreased permeability under prolonged submergence gave no evidence of soil aggregate breakdown due to purely physical causes. The reduced permeability appears to be due solely to microbial sealing. The soil pores probably become clogged with the products of growth, cells, slime, or polysaccharides. If the observed reduction in permeability was due in part to disintegration of soil aggregates, the dispersion is believed to be due to biological causes, that is, the attack of microorganisms on the organic materials which bind soil into aggregates.

Soils may be readily sterilized in the laboratory with ethylene oxide gas with no appreciable change in physical properties. For certain research purposes, this method offers advantages over that of steam sterilization.

135. ANONYMOUS. 1938. Irrigation with Sewage. *Engr. News-Record* 121:821.

A storage lake and land irrigation solved the sewage disposal problem at Kingsville, Texas. In this region of low rainfall and high evaporation, suitable streams for the disposal of sewage are practically nonexistent. The distribution and disposal system is described. The storage lake makes the system quite flexible. Disposal operations continue even when irrigation is not in progress.

136. ELDRIDGE, EDWARD F. 1947. Industrial Wastes – Canning Industry. *Ind. and Engr. Chem.* 39:619-624.

Canneries operate on a seasonal basis. Their wastes consist largely of washings from the preparation of products for canning. Waste volume and characteristics vary widely with the type of product packed. The material in the wastes consists largely of organic solids in suspension which cause objectionable conditions when they decompose. Effective screening should be a common practice with all cannery wastes. This may be followed by chemical precipitation, sedimentation, biological filtration, or lagooning, or a combination of these, depending upon the degree of treatment necessary. The required treatment is established by governmental agencies in each case.

Lagooning and irrigation are desirable in that the method completely eliminates stream pollution. Operating methods and cost figures are presented.

137. HEDGER, HAROLD E. 1950. Los Angeles Considers Reclaiming Sewage Water to Recharge Underground Basins. *Civil Engr.* 20:323-324.

Reclamation of waste water from sewage constitutes an important potential source of water for spreading and recharge of underground basins. Experimental tests have shown that the percolated effluent is bacteriologically safe within a depth of 7 feet from the ground surface. Irrespective of the groundwater recharge, it is proposed as a means of creating a freshwater barrier to seawater encroachment.

138. LUDWIG, RUSSELL G. 1950. Reclamation of Water from Sewage and Industrial Wastes in Los Angeles County. *Sewage and Ind. Wastes* 22:289-295.

Discusses the use of reclaimed waters for augmenting underground water resources, including beneficial use for industrial and agricultural purposes, which indirectly aids in building up groundwater reserves by curtailing existing draft on the underground basins. Excellent opportunities for industrial use exist in Los Angeles County, and such projects are under current study.

The direct recharge of underground basins through the use of natural sand filters seems especially significant for the following reasons:

1. The sand filters not only serve as the means of recharge but also act as a final check on water quality.

2. The vast underground water storage basins are most advantageously used in a storage capacity; thus, they allow intermittent operation of reclamation plants and at the same time maintain a firm water supply.

3. Finally, water so returned to the underground can be used for any beneficial purpose, including domestic consumption.

139. O'CONNELL, WILLIAM J., JR. and GRAY, HAROLD F. 1944. Emergency Land Disposal of Sewage. *Sewage Wks. Jour.* 16:729-746 (Reprinted from *Calif. Sew. Wks. Jour.*, Vol. 15, No. 2, 1943.)

The shifting of population during the war years brought on overcrowding in certain localities and overloading of waste treatment and disposal facilities. Land disposal should be considered as an emergency measure where these conditions exist. At the same time, the authors feel that land treatment or land disposal of sewage is legitimate, effective, practical, and worthy of consideration, especially for small cities in arid or semi-arid regions. They point out the basic principles, adaptability, and limitations, and present the fundamental factors in successful design and operation.

Land disposal may have as its primary purpose an agricultural operation or a disposal operation. Over-irrigation must be avoided. Intermittent application followed by cultivation is recommended for good soil condition and weed control. If properly operated, no appreciable odors should result from using a well-clarified effluent.

Discussions by C. G. Gillespie and W. T. Knowlton are included.

140. PEURIFOY, R. L. 1939. Sewage Irrigation as a Method of Disposal. *Proc. 21st Texas Water Works and Sewage Short School,* p. 115-121. Abst: *Sewage Wks. Jour.* 12:1018-1019.

Constituents in sewage that are beneficial to soil are listed, as well as certain others that are objectionable. Results of irrigation with sewage at Kingsville, Texas are described. Methods of application are varied. Condition of subsoil as well as texture of surface layer are important considerations. Reservoir for storage of at least three months' supply is recommended.

Sewage disposal by irrigation is safe, effective, and economical. Cities should seriously consider irrigation as a possible method of disposal.

141. SPENCER, B. R. 1943. Sewage Disposal by Irrigation. *Public Health* (South Africa) 7:15-28. Abst: *Sewage Wks. Jour.* 16:655-657.

Land disposal is necessary in South Africa since few places permit effluent to be discharged to streams. Reviews history of land disposal. First recorded sale of effluent for irrigation was at Bromford, England, in 1869.

Water requirements of different crops are considered. Over-irrigation has resulted in raised water tables and "brackish" soil conditions. Deep plowing has been employed to help alleviate the situation.

Italian rye grass has been found to be satisfactory. Its several advantages are enumerated.

142. WINSLOW, C. E. A. and PHELPS, E. B. 1906. Investigations on the Purification of Boston Sewage. *U. S. Geol. Survey Water-Supply Paper 185,* 163 pages.

One method of sewage disposal consists of distributing the sewage over broad areas and allowing the liquid to recharge the groundwater. The method has been widely used in Europe since the sixteenth century. Conditions for "sewage farming" are specially favorable in the arid portions of the western United States. Plants in Utah, California, and Wyoming are mentioned. In areas selected for sewage application, the soil should be light and the subsoil sandy or gravelly to obtain suitable recharge rates. Recharge rates in England range between 0.006 and 0.046 feet per day and in Germany between 0.006 and 0.021 feet per day.

1951 — 1955

143. BELL, JAMES W. 1955. Spray Irrigation for Poultry and Canning Wastes. *Public Works* 86:111-112. *PHE Abst.* 36:S:16.

Liquid waste disposal from two poultry-processing plants and a canning plant in Arkansas is described. In each case, septic tank failure and/or lagooning resulted in objectionable conditions. Plant wastes are screened and applied to the soil directly or by spraying. Rates of application vary from 10 to 60 inches per year; and 0.25 to 0.7 inches per day for short periods. Spray irrigation is considered a water conservation method. The three plants consider this method of disposal to be satisfactory and suitable where municipal disposal facilities are not available. Some monetary return is realized from the irrigated land.

144. BROWN, H. D., HALE, H. H., and SHEETS, W. D. 1955. Disposal of Cannery Wastes by Irrigation. *Food Packer* 36:28-30. *PHE Abst.* 36:S:37.

Four methods of irrigation now used are furrow, ditch, flood, and spray. The soil type and land contour determine the appropriate method to use. Stagnant water must be avoided. Vegetation assists in water disposal by transpiration and soil conditioning. Details are given on spray irrigation field tests. Costs are considered. Information is given on the best type of spray nozzle.

145. BUSH, A. F. and MULFORD, S. F. 1954. Studies of Waste Water Reclamation and Utilization. *Calif. State Water Poll. Control Bd., Sacramento, Publ. No. 9.* 82 pages. Abst: *Sewage and Ind. Wastes* 27:119.

This report covers the determination of (a) relationship of underground water pollution to methods and rates of spreading and percolation of reclaimed waste waters; (b) the effects on underground water pollution of increasing the percolation rates of reclaimed waste waters by means of cropping and vegetation, additives to top layers of soil, forced irrigation, or other means; (c) degree of contamination and/or pollution of a variety of truck crops on maturity where the reclaimed waste waters from various sources, including sewage and industrial wastes, have been applied to the crops and spreading areas by flooding, spraying, or other means; and (d) the extent of odor and other nuisances which may result from this procedure.

It is recommended that waste water be considered a water resource and that further studies be made of percolation rates and degree of treatment required to handle the pollution load, also to remove salts (particularly sodium and boron) from sewage and industrial wastes.

Useful references and a bibliography are included.

146. Canham, Robert A. 1955. Some Problems Encountered in Spray Irrigation of Canning Plant Wastes. *Proc. 10th Ind. Waste Conf.*, Purdue Univ. 89:120-134.

Seasonal operation requires that waste treatment systems have relatively low capital investment and reasonable operating cost. The organic loading may vary widely with different types of canning wastes. Other waste characteristics are discussed.

Considers the problems encountered in spray irrigation, such as availability of land, soil type, ground slope, frequency of application, cover crops, and spray distribution systems.

147. Dennis, Joseph M. 1953. Spray Irrigation of Food Processing Wastes. *Sewage and Ind. Wastes* 25:591-595.

Many food-processing plants are located in small towns where treatment plant facilities are not adequate to accommodate both industrial waste and domestic sewage. To discharge the wastes into small streams creates serious nuisance and pollution problems, especially in periods of low streamflow or dry periods. Disposal by spray irrigation has solved the problem for many processing plants. Examples are cited, and costs are discussed. The method must be adapted to the individual situation. The need for more research is recognized.

148. Dunstan, Gilbert H. and Lunsford, Jesse V. 1955. Cannery Waste Disposal by Irrigation. *Sewage and Ind. Wastes* 27:827-834.

Industries operating on a seasonal basis often produce wastes exceeding the capacity of municipal disposal facilities. Separate pretreatment or completely separate disposal may be required. Under such conditions, disposal of industrial wastes by irrigation may prove the most economical method. Several examples of cannery waste disposal by irrigation are cited.

Experiments were conducted at Dayton, Wash., in which cooled blancher waste water was used to irrigate alfalfa and permanent pasture test plots. The grass appeared to be less susceptible to the high organic loadings than was the alfalfa.

The authors attributed the killing effect of the blancher waste to high organic loading, similar to an over-application of fertilizer, although no proof of this was offered.

149. GOTAAS, HAROLD B., ET AL. 1953. Final Report on Field Investigation and Research on Waste Water Reclamation and Utilization in Relation to Underground Water Pollution. *Calif. State Water Poll. Control Bd., Sacramento, Pub. No. 6,* 124 pages. Abst: *Sewage and Ind. Wastes* 26:927-928.

Circular spreading basins, 19 feet in diameter, were constructed and equipped so that samples of the percolating liquid could be collected at various depths for bacteriological and chemical analyses. Spreading was studied with three liquids: fresh water; sewage treatment plant final effluent having a BOD of about 10 ppm; and settled sewage with a BOD of about 100 ppm. A number of operating variables were studied to determine the conditions which gave maximum percolation rates and minimum contamination or pollution of the groundwater. These included (1) nature of liquid, (2) length of spreading period, (3) length of resting period, and (4) effect of surface treatment such as spading, sand cover, and application of soil stabilizer.

Some of the conclusions were:

1. A bacteriologically safe water can be produced from settled sewage or final effluent if it passes through at least 4 feet of soil.
2. A water of satisfactory chemical quality can be produced providing high concentrations of undesirable industrial wastes are not included in the raw sewage.
3. A highly treated sewage effluent must be used to obtain high rates of percolation.
4. A percolation rate of 0.5 acre-ft. per acre per day can be expected when spreading a final effluent on Hanford fine sandy loam.
5. The optimum method of operation is to spread continuously for about a month, allow the basin to rest until moisture content approaches permanent wilting point, then cultivate the dry soil. Continuous application of effluent may then be carried on for as long as 6 months. Resting and cultivation may then be repeated.
6. Mosquito control will be necessary, and algae control may be required.
7. Study was conducted on Hanford fine sandy loam. Further investigations would be necessary to generalize the findings to include other soil types.

150. GREENBERG, ARNOLD E. and THOMAS, JEROME F. 1954. Sewage Effluent Reclamation for Industrial and Agricultural Use. *Sewage and Ind. Wastes* 26:761-770.

Planned reclamation is designed to produce a usable water from sewage. Such reclaimed waters may be used by industry or agriculture "directly" or "indirectly." The latter involves replenishing groundwater basins from which industrial, agricultural, or domestic supplies are drawn.

Experiments performed by the University of California's Sanitary Engineering Research Laboratory are discussed, and the conclusions are summarized:

1. A bacteriologically safe water can be produced from settled or more highly treated sewage if the liquid passes through at least 4 feet of soil.
2. A water of chemical quality satisfactory for most uses can be produced from settled sewage or final effluents, provided high concentrations of undesirable wastes are not included in the raw sewage.
3. To obtain relatively high rates of percolation, a highly treated sewage plant effluent must be used for spreading.
4. A percolation rate of 0.5 acre-ft. per acre per day, can be expected when spreading final effluent on Hanford fine sandy loam.
5. The optimum method of operation is to spread continuously for a month, preferably with liquid containing large amounts of organic matter, then to allow the basin to rest until it is air dried. Thereafter, cultivation of the dry soil is desirable. Following this preliminary treatment, continuous application of a final effluent may be carried on for as long as 6 months. Resting and cultivation may then be repeated.
6. Mosquitoes in spreading basins will create a nuisance and health hazard unless control measures are adopted. If algal odors are pronounced, the control of algae also may be necessary.
7. Further investigation is needed of sewage percolation in different soils and of phenomena associated with the movement of water into such soils to generalize the conclusions reached as a result of this study with Hanford fine sandy loam.

151. GREENBERG, ARNOLD E. and McGAUHEY, P. H. 1955. Chemical Changes in Sewage During Reclamation by Spreading. *Soil Sci.* 79:33-39.

In arid and semi-arid regions, treated sewage is spread on the ground and the water percolates down to the groundwater. Results of chemical analyses of percolating liquids in four spreading basins in California are tabulated. Samples were collected and analyzed to a depth of 13 feet. Concentrations of Ca, Mg, Na, and Cl ions remained the same. K decreased by 50 percent. Ammonia and P were completely removed within the first 4 feet. Sulphates and bicarbonates increased by 30 percent and nitrate by about 200 percent. Nitrification accounts for the increase in nitrate. It is suggested that these changes are due to biological activity in the soil.

152. LOWE, ROBERT P. 1952. Pollution Control of the Rio Grande in New Mexico. *Sewage and Ind. Wastes* 24:1021-1024.

Irrigation of agricultural crops is by far the major use of water on the Pecos and Rio Grande rivers in New Mexico. Water shortages have limited industrial development that must depend on adequate water supply. The demand for use of all available water in New Mexico, Texas, and the Republic of Mexico necessitates close control of pollution so that the maximum usage of water may be obtained. This need has been reflected in New Mexico through constant demands for use of sewage effluents for irrigation. Growth is expected to continue, increasing the need for domestic sewage and industrial waste treatment facilities. Only continued and alert control can prevent extensive problems from being created.

153. MATHER, JOHN R. 1953. The Disposal of Industrial Effluent by Woods Irrigation. *Trans. Amer. Geophys. Union* 34:227-239. Reprinted: *Proc. 8th Ind. Waste Conf.*, Purdue University 83:439-454.

The author describes the design and operation of a disposal system for the Seabrook Farms Co., Seabrook, New Jersey in which food processing wastes are sprayed over wooded lands. The forest soils were selected for their much higher water absorbing and holding capacity. The spreading of 400 to 600 inches of water onto forest soil during an eight-month period caused a rise in the water table, but did not seriously harm the vegetation, clog the soil, or result in swamps or a completely saturated soil. Vegetative growth increased after second and third year of operation. The water table returned to its original level during the four winter months when operations ceased.

Waste disposal by woods irrigation at Seabrook is entirely satisfactory. With careful study and planning, other types of nontoxic, organically polluted wastes might be successfully disposed of in a similar operation.

154. MILLER, PERRY E. 1953. Spray Irrigation at Morgan Packing Company, Austin, Indiana, *Proc. 8th Ind. Waste Conf.*, Purdue. 83:284-287.

The plant operates the year round, processing beans, soups, hominy, beets, etc., plus a seasonal pack of tomato products. The company installed a spray irrigation system for disposing of cannery wastes in 1952. The system's appealing features were its simplicity and the possible solving of a stream pollution problem. The estimated waste flow was 1.3 million gallons per 16-hour day. Details of the installation are given. The rate of application of the sprinkler system was 0.44 inch per hour. Two sprinkler lines were operated while two others were being moved to new locations. There was no appreciable odor or insect problem in the irrigated fields. In the irrigated area, Kentucky fescue grew to twice the height of that in the area that had not received plant wastes.

155. NELSON, LEONARD E. 1952. Cannery Wastes Disposal by Spray Irrigation. *Wastes Engr.* 23:398-400. *PHE Abst.* 32:S:74-75.

In 1951, an installation in Minnesota used 24 million gallons of cannery waste waters to irrigate 110 acres of crops. Crop yields were increased, and no nuisance odors resulted. Portable aluminum pipe was used for sprinkler lines. The pipe was moved as required to control distribution of water to the crops. Cost data are given for the installation.

156. ORLOB, G. T. and BUTLER, R. G. June 1955. An Investigation of Sewage Spreading on Five California Soils. *SERL, Univ. of Calif., Tech. Bull. No. 12*, I.E.R. Series 37, Berkeley.

The infiltration rate for each soil was found to follow the same general pattern: (1) an abrupt decrease in rate attributed to dispersion of soil particles; (2) an increase in rate due to solution of entrapped gases into the percolating liquid; and (3) a decrease due to accumulation of biological slimes in the soil voids. Infiltration rates in the third phase ranged from 30 feet per day for the most permeable soil to 0.6 feet per day for the fine soils.

Infiltration of settled sewage applied to soil lysimeters decreased sharply due to clogging of soil surface by particulate matter. Coliform removals were generally highest in the fine soils. Increases in calcium and magnesium concentrations and decreases in sodium and potassium concentrations in the percolates were observed.

Aerobic conditions existed for the first few weeks of sewage spreading after which anaerobic conditions persisted. Increases in BOD in the effluents from the soils were obtained after the anaerobic stage predominated. Organic matter penetrated the surface strata of the lysimeter soils, causing decreases in permeability and infiltration rates. Abrupt loss in hydraulic head through surface strata was experienced for all soils receiving the sewage application.

Particle-size characteristics of the five soils studied could not be correlated with the observed infiltration rates. Therefore, field performance of a soil cannot be predicted by comparing its particle-size characteristics with those of other soils for which infiltration rates have been established.

157. Reploh, H. 1955. Land Treatment of Sewage. *Kommunalwirtschaft*, No. 8, 401. *Water Poll. Abst.* 29:352 (1932).

The author discusses the advantages of agricultural utilization of sewage, methods of preventing odor nuisance and spreading of bacteria, and the importance of this method of disposal to the groundwater supply.

158. Sanborn, N. H. 1953. Disposal of Food Processing Wastes by Spray Irrigation. *Sewage and Ind. Wastes* 25:1034-1043.

Spray irrigation has provided a means for the disposal of food-processing wastes which does not pollute streams or create odors. The method can be extended to certain other industrial wastes. Several examples of successful disposal operations are cited.

Disposal systems for typical food-processing plants are described and cost figures given. Certain problems and limitations of spray irrigation systems are discussed.

159. Steel, Ernest W. and Berg, E. J. M. 1954. Effect of Sewage Irrigation on Soils. *Sewage and Ind. Wastes* 26:1325-1339.

The relatively small changes in the soils studied indicate that sewage irrigation is neither especially beneficial nor injurious to soils. Sewage irrigation encourages accumulation of chlorides. Leaching of the chlorides was readily accomplished and there should be no injurious accumulations under normal operation. A slight increase in organic matter (humus) can be expected.

Pore space is increased by sewage irrigation, and crumb structure shows some improvement.

Sewage-irrigated soils accumulate slightly more phosphorous than water-irrigated soils. Boron also will be contributed to soils by sewage.

160. STONE, RALPH. 1953. Land Disposal of Sewage and Industrial Wastes. *Sewage and Ind. Wastes* 25:406-418.

The author discusses the disposal of waste effluents by irrigation of restricted crops, or within spreading areas. Soil organisms and filtration provide a "high-quality, fully oxidized, pathogen-free, nonturbid water" Intermittent dosage assures an aerobic environment which is required for nuisance-free disposal. Several examples are cited along with data describing operations. Variable factors important to the design and operation of land disposal facilities are discussed.

Nuisance and health hazards may be controlled through proper design and technical supervision of the operation. Certain highly mineralized industrial wastes may present special problems. Land disposal methods appear to be satisfactory for domestic sewage effluent.

161. TALATI, R. P. 1954. Effect of Sewage Irrigation of Soil Profiles. *Proc. of Ninth Meet. Crops Soils Bd. Agric. India,* March 1952, 156-160. *Soils and Fertilizers* 18:50 (243), 1955.

Studies have shown that sewage irrigation improves soil condition, provided suitable crop rotations and proper cultivation methods are used.

1956 — 1960

162. CANHAM, ROBERT A. 1959. Industrial Waste Disposal by Spray Irrigation. *Southwest Water Wks. Jour.* 41:14-16, 18, 20, 22 (Dec.). *PHE Abst.* 40:S:89-90.

The author discusses the many advantages of waste disposal by spray irrigation. Among these are: (1) affords complete and adequate treatment (2) minimizes offensive odors; (3) cost of operation compares favorably with other disposal methods; and (4) does not require highly trained personnel.

Soil characteristics and cover crops are important considerations for successful operation. Recommends that waste waters be screened before spraying.

163. CHASE, WILLIAM J. 1960. Spray Disposal of Domestic Wastes. *Pub. Works* 91:137-141 (May). *PHE Abst.* 40:S:107.

Emphasizes the need for proper disposal methods in relation to spray irrigation of pasture and wooded areas with domestic wastes. Requirements are given in regard to pretreatment; allowable volumes according to conditions, spray-nozzle arrangement, prevention of harm to foliage, and other details of application. Deep silty soil is preferable. Clay subsoil may lead to bad effects from adsorption of sodium through ion-exchange.

164. DIETZ, MAX R. and FRODEY, RAY C. 1960. Cannery Waste Disposal at Gerber Products. *Compost Science* Vol. 1, No. 3, p. 22-25.

Spray irrigation as a means of disposing of cannery wastes has given satisfactory results at the Fremont, Michigan plant of Gerber Products Company. The operation is described.

165. GELLMAN, I. and BLOSSER, R. O. 1959. Disposal of Pulp and Papermill Waste by Land Application and Irrigation Use. *Proc. 14th Ind. Waste Conf.*, Purdue Univ. 104:479-494.

Some of the reasons for increased attention being given land disposal of mill effluents are briefly reviewed. Factors considered important to such disposal are: physical characteristics of the soil, microbial activity, and organic decomposition in the soil. Current land and crop irrigation practices are discussed. Water quality as required for irrigation and the problem of water salinity are considered. Results of 18 mill studies are summarized and additional studies suggested.

166. HICKERSON, R. C. and MCMAHON, E. K. 1960. Spray Irrigation of Wood Distillation Wastes. *Jour. WPCF* 32:55-64.

Spray irrigation seems particularly suited for nontoxic, high BOD, water soluble organic wastes. Greenhouse and field tests were run using fescue, blue grass, rye grass, and ladino clover.

Utilization of these wastes for irrigation greatly alleviated a stream pollution problem. It proved a useful and practical means for industrial waste disposal at the Wrigley wood distillation plant.

Steps to be followed in evaluating a particular waste disposal problem are suggested.

167. JOHNSON, CURTIS E. 1957. Utilizing the Decomposition of Organic Residues to Increase Infiltration Rates in Water Spreading. *Trans. Amer. Geophys. Union* 38:326-332.

Decomposition rates were determined for several plant residues which were incubated under controlled conditions in the absence of soil. Three, ranging in rates from high to low, were mixed with soil and incubated. Decomposition rates with soil were similar to those without soil. Microbial counts made during decomposition of the plant residues in soil showed the greatest number of microorganisms occurred in the soils containing plant residues which decompose rapidly. Ammonium nitrate mixed with the soil stimulated decomposition slightly.

Percolation rates of soil mixed with organic residues varied with the amount of material applied, decomposition rate of the material, and length of the incubation period. The studies indicate that initial decomposition at a moisture content near field capacity, followed by decomposition at near saturation, produces the highest infiltration rate for a given amount of organic residue. Data are given and the use of organic residues to increase the infiltration rate of water-spreading areas is discussed.

168. McDowall, F. H. 1958. Dairy Wastes: Disposal by Spray Irrigation on Pasture Land. *Dairy Engr.* 75:251-254, 266. *Dairy Sci. Abst.* 20:923. *PHE Abst.* 39:S:36.

The author discusses the disposal of effluents from New Zealand dairies by irrigation and describes a typical installation using high-pressure rotating sprays and a suitable irrigation technique. He gives the reasons why this method is particularly applicable in New Zealand.

169. McKee, Frank J. 1957. Dairy Waste Disposal by Spray Irrigation. *Sewage and Ind. Wastes* 29:157-164.

Disposal of dairy wastes by spray irrigation has proved satisfactory for remote areas having no access to sewers. Stream pollution has been reduced, and pasture land improved by the practice. Spray irrigation systems are described, and numerous typical installations are cited. Land area needs are discussed regarding slope, soil type, and vegetation. Winter operation is considered also.

Application of wastes varies from 2,500 to 10,000 gpd per acre, depending on soil and vegetation. There are no runoff or odor nuisances under normal conditions.

170. Monson, Helmer. 1960. Cannery Waste Disposal by Spray Irrigation. *Compost Science* Vol. 1, No. 1, p. 41-44.

Ten years of spray irrigation by a large cannery show that this method has increased promise for conserving water, reducing stream pollution, and enhancing soil fertility. The economical operation holds considerable appeal for canners.

171. Orlob, Gerald T. and Butler, Robert G. 1956. Use of Soil Lysimeters in Waste Water Reclamation Studies. *Jour. San. Engr. Div., Proc. Amer. Soc. Civil Engr.* 82:SA3:1002.

Soil lysimeters were found to provide a convenient and inexpensive means of studying the fundamental behavior of soils under various conditions of water and sewage spreading. They were shown to be of value in estimating the performance of soils under large-scale spreading operations.

The lysimeters were constructed of corrugated iron pipe sections, 3 feet in diameter and 5-feet deep. Twenty lysimeters were used to study the characteristics of five agricultural soils under various loading conditions with fresh water and clarified effluent from primary-treated municipal sewage.

Data are presented in infiltration rate versus time curves. The methods and results are discussed.

172. Peter, Yehuda. 1958. A Report of Present Activities in Israel. *Water and Sewage Works* 105:493.

The primary effluent from a number of sewage treatment plants is pumped to a 55-acre sand dune at the rate of 2,000 to 2,500 gpd/acre. Sandy loam underlies the dune at depths of 13 to 23 feet. The annual rainfall averages 20 inches. Cattle fodder is grown, and a good humus layer formed during the first year of cultivation, helping to stabilize the shifting sands.

A natural depression is used as an experimental percolation area. Sewage effluent is applied at the rate of 85,000 to 100,000 gpd/acre, ten times the agricultural irrigation rate. This raises the freshwater table and prevents saltwater intrusion.

173. SIMMERS, R. M. 1960. Effluent Disposal by Irrigation. *New Zealand Engr.* 15:410-413.

The author describes a scheme whereby slaughterhouse wastes are disposed of by irrigation over grazing land. Fodder growth has been extraordinary, being capable of grazing over 20 sheep per acre. No nuisance has been apparent, and no stock troubles have been encountered in grazing cattle or adult sheep on the area.

In suitable localities, irrigation with clarified effluent from anaerobic digesters should be considered. The readily available nitrogen would be higher, and the risk of stale areas from ponding would be reduced.

174. STONE, A. R. 1960. Land in Sewage Purification, *Jour. Inst. Sewage Purif.* (British) Part 4:417-424.

The author cites British experience with land disposal and discusses reasons behind several monumental failures. The agricultural disposal of sludge is dealt with in some detail and is recommended as an integral part of land disposal of sewage.

Experience at Nottingham is described in detail, where sludge disposal and irrigation with effluent have been studied.

175. TODD, DAVID K. 1959. Annotated Bibliography on Artificial Recharge of Groundwater Through 1954. *U. S. Geol. Survey Water-Supply Paper 1477,* 115 pages.

The author lists the various methods used in artificial recharge operations and considers the factors that are important in the selection of the method. The bibliography lists the literature pertaining to artificial recharge of groundwater up to and including the year 1954. Each reference is abstracted, authors are listed alphabetically, and an index based on subject and locality is included. The blibliography section covers pages 5 through 107 of the report.

1961 — 1965

176. ANONYMOUS. 1964. Effluent Treatment by Spray Irrigation. *Water and Waste Treatment* 10:105.

Spray irrigation is employed in New Zealand as an effective and economical method of treatment and disposal of a variety of trade wastes.

Initial BOD values are in some cases very high. The BOD values of drainage from the fields and of nearby rivers receiving the drainage are closely checked and found to be satisfactory. Up to 65,000 gpd are being disposed of in this way, using land areas of 3 to 60 acres. The technique is successful on a variety of soil types and in locations near rivers. In most cases, the effluent is used on grassland, which is exploited by grazing livestock. Lagooning may be employed as a means of reducing pollution before spraying. Several specific examples are cited with details of operation.

177. BLOSSER, RUSSELL O. and OWENS, EBEN L. 1964. Irrigation and Land Disposal of Pulp Mill Effluents. *Water and Sewage Wks.* 111:424-432.

Interest in land disposal of many industrial wastes has increased in recent years. For the many industrial wastes that are unsuitable for agricultural irrigation purposes, the primary concern is disposal. Paper mill effluents fall in this category, usually having a high sulfite content and low pH.

Laboratory studies dealt with changes in effluent characteristics, in soil characteristics, and in cover vegetation conditions when a wide variety of effluents were applied to the soil in simulated irrigation practice. Grasses were used for cover vegetation. *Alta fescue* was found to have high moisture resistance and reasonably high salt tolerance with an extensive root system. Results of the study are discussed.

178. BOCKO, J. and SZERSZEN, L. 1962. Chemical Changes in Soil Irrigated with Municipal Sewage. *Zesz. Nauk. Wyz. Szkol. Rol. Wroclaw Melior* 7:71-82. *Soils and Fert.* 26:273 (1982), 1963.

No significant changes were observed in humus and nutrient content in the soil after sprinkling with sewage at low rates of application; but alkalinity increased slightly, especially in the deeper soil layers. In filtration fields, because of the high sewage load, organic substances accumulated in the soil and the sorption capacity increased. A constant supply of sewage resulted in a decrease in pH. No accumulation of alkalis occurred in light-soil filtration fields.

179. BOCKO, J. 1965. Displacement of Iron in Soil Irrigated with Sewage. *Zesk. Nauk. Wyzsz. Szk. Roln. Wrocl. Melior* 10:209-217, *Soils and Fertilizers* 29:82 (527), 1966.

Decomposition of sewage in soil causes oxygen deficit, resulting in a reduction of Fe^{3+} and leaching of Fe^{2+} to the lower horizons. The displaced Fe accumulates in the lower horizons, forming an impermeable layer inhibiting water percolation into the drains.

180. FISK, WILLIAM W. 1964. Food Processing Waste Disposal. *Water and Sewage Wks.* 111:417-420. *PHE Abst.* 45:68 (1965).

Two methods of waste disposal are employed at Gerber Company plants. At Asheville, North Carolina, the wastes are ground, solids removed, and used for animal feed. The waste water is discharged to the French Broad River.

At Fremont, Michigan spray irrigation is employed. Large solids are removed for animal feed. Waste water is pumped to a 140-acre site having 50-ft. depth of Ottawa Sand. Sprinklers are spaced at 120 ft. and deliver 81 gpm over an area 210 ft. in diameter. Several cover crops have been grown. Solids accumulation and surface compaction require "subsoiling" the spray area every 2 or 3 years. Test wells 500 ft. from the spray area reveal no measurable effect on groundwater level or quality.

181. HUSEMANN, C. and WESCHE, J., 1962. The Purifying Effect of Different Methods of Sewage-Water Treatment in Investigations of Berlin Sand Soil. *Z. Kulturtech* 3:291-307. *Soils and Fertilizers* 27:153 (1097), 1964.

Surface flooding (soil filters), border irrigation, contour-furrow irrigation, sub-irrigation, and sprinkling irrigation were compared. Soil filters were unsatisfactory, leaving a high content of N and other plant nutrients in the seepage water. The other irrigation methods were better; but, by far, the best was sprinkling irrigation which resulted in almost complete purification of the seepage water.

182. JONES, JOE H. and TAYLOR, GEORGE S. 1965. Septic Tank Effluent Percolation Through Sands Under Laboratory Conditions. *Soil Sci.* 99:301-309.

In a gravel-sand column in which septic tank effluent first percolates over the gravel, the zone of most rapid clogging is the sand-gravel interface. Organic and inorganic deposits are also highest in the interfacial region. The gravel accumulates up to 20 per cent of the total deposits, and because of its better aeration affords higher organic decomposition. Soil clogging under effluent loading occurs 3 to 10 times faster under an anaerobic than under an aerobic environment, and sands of initially high hydraulic conductivity are clogged at a much slower rate than those of initially low conductivity.

Under aerobic conditions, there are three distinct phases of clogging in sand. The first is a period in which the conductivity declines to near 25 percent of its initial value. During the second phase, the conductivity fluctuates near the latter value for many months and declines slowly to near 10 per cent of the original conductivity. In the third phase, the conductivity drops rather sharply to 1 or 2 percent of its initial value. Under anaerobic conditions, the second phase of clogging is absent, and the first and third phases are indistinguishable.

183. KLEIN, STEPHEN A., JENKINS, DAVID, and MCGAUHEY, P. H. 1963. The Fate of ABS in Soils and Plants. *Jour. WPCF* 35:636-654.

Adsorption and bio-degradation of alkyl benzene sulfonate (ABS) from water percolating through each of five soil types under saturated and unsaturated, sterile and biologically-active, and under continuous and intermittent flow conditions were studied. The results are discussed and significant conclusions enumerated. Water solutions of ABS were compared to primary sewage effluents containing added amounts of ABS on both fertilized and unfertilized soils. Sunflower and barley were grown in water culture at ABS concentrations of 0, 10, and 40 mg/1. Sunflower, barley, and *Lupinus albus* were grown in soil at ABS concentrations of up to 50 mg/1. Although ABS severely inhibited growth in water culture, only sunflower was adversely affected in soil. Growth of plants irrigated with sewage far surpassed those irrigated with water, regardless of soil fertilization practices or the addition of up to 15 mg/1 ABS to the sewage. It was concluded that irrigation with sewage is beneficial to plants despite the presence of ABS in any amount likely to occur in sewage at the present time.

184. LULEY, H. G. 1963. Spray Irrigation of Vegetable and Fruit Processing Wastes. *Jour. WPCF* 35:1252-1261.

A large food-processing company uses spray irrigation for waste disposal at two of its eastern factories. Experience indicates that the method can be operated successfully even though the soil and terrain were not considered optimum for the spray fields. It has been used for year-round disposal in the climate of southern Pennsylvania and New Jersey. Disposal by spray irrigation is practical, simple in concept, and straightforward in operation. Through careful planning and control, it can be adapted to various ground conditions and terrain. The wastes must not be toxic to ground-cover vegetation. The land required for disposal operations should be available at a reasonable price and in close proximity to the factory site.

185. PARKHURST, JOHN D. 1963. Reclaiming Used Water. *Amer. City* 78:83-85 (Oct.). *PHE Abst.* 44-153.

The Whittier Narrows plant in Los Angeles is designed to salvage the treated waste water for reuse rather than dump it into the ocean. A constant 10 mgd of raw sewage is diverted from the trunk sewer to the activated sludge plant, which consists of 2 primary sedimentation tanks (detention 2.6 hr), 3 aeration tanks (25 percent return, detention 5.8 hr), and 5 final settling tanks (detention 2.2 hr). This treatment, followed by chlorination, produces an effluent averaging about 10 mg/liter BOD and soluble solids. Percolation through the ground after spreading recharges the aquifer for underground storage and further reduces the impurities. All by-products (e.g., sludge) go back into the trunk sewer for removal and disposal at existing downstream treatment facilities.

186. ROBECK, GORDON G., COHEN, JESSE M., SAYERS, WILLIAM T., and WOODWARD, RICHARD L. 1963. Degradation of ABS and Other Organics in Unsaturated Soils. *Jour. WPCF* 35:1225-1236.

Soil lysimeter studies showed the alkyl benzene sulfonate (ABS) in a septic tank effluent can be degraded from 5 to 35 mg/1 to less than 0.5 mg/1 if applied properly to certain unsaturated soils. Under intermittent loading on a daily basis aerobic organisms survived. Most sandy soils handled at least 0.5 to 1.0 foot per day of waste. Organisms usually found in sewage and soil were able to degrade ABS, 2,4,5-T, 2,4-D, and o-cresol if time were allowed to adjust and handle new organics in the waste. Coliform organisms, odor, turbidity, and COD were greatly reduced and nitrification took place when the ABS was degraded below 0.5 mg/1.

187. ROBECK, GORDON G., BENDIXEN, THOMAS W., SCHWARTZ, WARREN A., and WOODWARD, RICHARD L. 1964. Factors Influencing the Design and Operation of Soil Systems for Waste Treatment. *Jour. WPCF* 36:971-983. Soil lysimeter studies with septic tank effluent indicate that soil systems can degrade the new synthetic organics as well as the usual COD components. It appears that groundwater can be protected when wastes are properly applied to the soil. Several important design and operational features are listed which will help effect a 90 to 95 percent reduction of ABS and other COD components in a septic tank effluent and also protect the groundwater from microbial forms.

188. ROHDE, G. 1962. The Effects of Trace Elements on the Exhaustion of Sewage-Irrigated Land. *Jour. Inst. Sew. Purif.* Pt. 6, 581-585. *Water Poll. Abst.* 36:421 (2063).

At the Berlin sewage farm, some of the soil has recently shown signs of exhaustion, and crop yields have fallen. Samples of exhausted soil and soil on which healthy plants were growing were examined, particularly for trace elements. The results were compared with analyses of similar samples from a sewage farm in Paris where signs of exhaustion had also been observed. The soil at the Berlin farm is sandy and acid, while that at the Paris farm is rich in lime. The results of the analyses are tabulated and discussed. It appears that the main cause of exhaustion at both Berlin and Paris is the presence of high concentrations of copper and zinc.

189. SCHRAUFNAGEL, F. H. 1962. Ridge-and-Furrow Irrigation for Industrial Waste Disposal. *Jour. WPCF* 34:1117-1132.

Where the soil is suitable and conditions favorable, ridge-and-furrow irrigation can accomplish a consistently high degree of treatment at low cost and with little maintenance. In some cases, a complete job of disposal can be accomplished. The history of the method is traced, and its use in disposal of canning, dairy, meat processing, municipal, and other wastes is discussed. Design, application rates, and tile drainage are considered, in addition to vegetation and water quality for irrigation. The method, in many cases, has been the solution to chronic pollution and nuisance problems.

190. SCOTT, RALPH H. 1962. Disposal of High Organic Content Wastes on Land. *Jour. WPCF* 34:932-950.

The author describes the practical aspects of strong waste application to land and cites experience gained from the practice. Disposal of liquid digested sludge, cheese whey, and spent sulfite liquor is discussed. Examples and cost figures are given. Careful planning is needed to safeguard groundwater quality, especially where spent sulfite liquor is involved.

191. SPRIVASTAVA, P. B. L. and MEHROTRA, C. L. 1962. The Effect of Leaching Saline Alkali Soils with Irrigation Waters of Different Kinds on the Permeability and the Composition of the Soils and the Composition of the Leachates. *Jour. Indian Soc. Soil Sci.* 10:93-98. *Soils and Fertilizers* 26:27 (189), 1963.

Results of laboratory tests are reported on the effect of leaching with sewage, canal, and well waters, in the absence or presence of ½ to 1 ton Ca SO_4, on the conductivity, Ca + Mg, monovalent cation and anion contents and percolation in different soils (pH 8.3-8.85) of originally 31-51 percent saturation.

Canal waters tended to increase soil alkalinity, but improved percolation, especially in combination with small doses of $CaSO_4$. Sewage waters decreased salinity and alkalinity in soils affected by the application of canal waters.

192. STANBRIDGE, H. H. 1964. From Pollution Prevention to Effluent Reuse. *Water & Sewage Wks.* 111:446-451 and 494-499. *PHE Abst.* 45:112-113.

Recent methods and future proposals for the reuse of effluents that now pollute England's rivers are presented. The need for greater conservation of water resources is discussed in relation to the rapidly growing needs of industries and the public in various areas of England and Wales. The author concludes: "As the demand for water increases and sewage effluents and river water are used more extensively, quality will be determined by the use to which the water is to be put rather than by the need to prevent nuisance or support fish."

193. STEFFEN, A. J. 1964. Control of Water Pollution by Wastewater Utilization: The Role of the WPCF. *Water and Sewage Works* 111:384-385.

As the 1965 President of the Water Pollution Control Federation, the author states: "Reclamation of wastewater by recharging groundwater basins, by irrigation, and by direct use as industrial water supply eliminates the wastewater from surface streams and thus qualifies as complete pollution control." He encourages the further development of methods for wastewater reclamation and criteria for its reuse. The Federation and its member associations continue to encourage reuse studies through publications and awards.

194. WATSON, JOHN L. A. 1964. Solving a Pollution Problem in Israel. *Effl. and Water Treat. Jour.* 4:126-127, 146. *Water Poll. Abst.* 38:229 (1114).

Before the construction of a sewage treatment plant at Haifa, Israel, the river Kishon was heavily polluted with domestic sewage which was discharged untreated or after primary treatment only. The new plant, treating domestic sewage and some industrial wastes, provides complete treatment by high-rate biological filtration. It is planned to use the effluent for irrigation and industrial purposes. Effluent is presently being used successfully in two fish-breeding ponds. Sludge is digested, dried on beds, and sold for composting with refuse.

195. WEISS, RUDOLPH W. 1961. Using Treated Sewage Effluent for Crop Irrigation. *Compost Science* Vol. 2, No. 3, p. 33-34.

The city of Kerrville, Texas solves a stream pollution problem and provides water for growing crops at the same time. In 1952 the Soil Conservation Service assisted the city in planning an irrigation program on its 320-acre farm. The treatment plant design and operation are given.

The wet digested sludge is diluted with sewage effluent and discharged onto the land in conjunction with the regular irrigation program, thereby eliminating the need for sludge drying beds and the tedious labor involved. The operation won Kerrville an award for the most efficient disposal of sewage sludge in the State of Texas.

196. WESTENHOUSE, RAY. 1963. Irrigation Disposal of Wastes. *TAPPI* 46:160A-161A. *PHE Abst.* 44:72 (1964).

Land disposal of kraft mill condensates was accomplished by sprinkler irrigation methods. Application rates of 0.5 in./day produced slight surface flooding. Sixty acres of land provided sufficient pasture for 80-100 head of livestock. Burning of vegetation by the 150°F condensates was controlled by the use of higher system pressures and increased trajectory from the nozzle outlet. More than 50 percent of the total mill waste load was disposed of on land by this method.

197. WISCHMEIER, W. H. and MANNERING, J. V. 1965. Effect of Organic Matter Content of the Soil on Infiltration. *Jour. Soil and Water Conserv.* 20:150-152.

Measurements of soil physical properties were obtained from 44 different soils and related to runoff. Soil texture classes included sandy loam, loam, silt loam, clay loam, silty clay loam, and silty clay. Organic matter contents ranged from 1 to 4 percent, and slopes from 4 to 14 percent.

The organic matter content of the soil was the measured variable most closely correlated with runoff. Results of linear regression analyses are discussed.

The study indicated that the entry of rain into the soil was influenced much more by the organic matter content and by management practice than by texture and topography.

4

Sanitary Aspects of Waste Water Utilization

Agricultural utilization of sewage treatment plant effluent should not be confused with sewage disposal. The two are not synonymous. Irrigation with sewage effluent, on the contrary, should be considered as a corollary of sewage disposal. In years past, irrigation first was used primarily as a convenient and relatively inexpensive method of disposing of sewage; but, as knowledge of the spread of disease increased, health standards were updated. Health authorities are generally agreed that water not safe enough to discharge into surface streams is unsafe for general irrigation use. Sewage for general irrigation use, therefore, requires pretreatment, such as is commonly given before discharging it to streams. In such cases, use is made of waste water which, for all intents and purposes, the city has already discarded.

In a few places irrigation is still used as a partial solution to municipal sewage disposal. Elsewhere, it is more properly an agricultural consideration. The use of sewage effluent on the farm, either as a permanent or supplemental water supply, is a matter of agricultural engineering design and planning.

On the other hand, the primary purpose of sewage disposal is to avoid health hazards. After all health factors have been adequately safeguarded to the satisfaction of State and local authorities and the waste water has been released by the city, there is no reason why it should not be made available for supplemental irrigation use—especially in arid regions where it may be an economic asset. The economic feasibility, however, must be determined for each individual case. One further consideration is that of water rights, which of course are governed by local law.

Public interests in irrigation with sewage effluents, then, are twofold: the efficient utilization of supplemental water supplies for crop production and, above all, the safeguarding of public health. The latter necessitates strict conformance with State health regulations and local sanitary requirements. The State health authority should be consulted in each case to determine which regulations apply.

A review of the literature covered in this bibliography leads to the following conclusions regarding the sanitary aspects of sewage irrigation:

(a) Raw, untreated sewage should never be used for irrigation regardless of the crop grown.

(b) Sewage effluent receiving at least primary treatment may be used for irrigation of crops not for human consumption.

(c) The use of primary treated, and preferably completely treated, sewage effluent on feed and pasture crops for animal consumption is considered safe and should be encouraged.

(d) If handled properly, the use of treated sewage effluent will not be hazardous to the operators.

(e) Properly treated and clarified sewage effluent may be rendered bacteriologically safe for use on any irrigated crop by chlorination after treatment. The practice should be routine as a safeguard of public health whenever the effluent is to be used for crop irrigation. Chlorination simply removes any uncertainty.

Abstracts

Prior to 1951

198. CRAWFORD, A. B. and FRANK, A. H. 1940. Effect on Animal Health of Feeding Sewage. *Civil Engr*. 10:495-496.

A study was conducted at the U. S. Department of Agriculture's Beltsville Research Center in which swine and cattle remained in good condition after a severe six-month feeding period including raw sewage, treatment plant effluent, and sludge. This study concluded that virulent bacteria were not present in sufficient concentration in the incoming sewage, effluent, or sludge of this sewage treatment plant to cause disease in susceptible animals. These test animals were subjected to a more severe exposure to effluent than would normally be expected to occur.

199. DIEHL, PAUL A. 1936. Treatment Required for Sewage Reused for Irrigation Purposes. Abst: *Sewage Wks. Jour*. 8:503.

About 100 cities, most of which are in California and Texas, use sewage for irrigation purposes. Oil and grease should be removed as well as all solids that might settle out in the irrigation ditches. For use on garden crops, the sewage should be sterilized and filtered.

200. Falk, Lloyd. L. 1949. Bacterial Contamination of Tomatoes Grown in Polluted Soil. *Amer. Jour. Pub. Health* 39:1338-1342.

The concentration of coliform bacteria on the surfaces of tomatoes grown in polluted soil indicated no abnormal gross contamination. Even when sprayed with fecal suspensions, surface coliform counts were no greater after one month than on control tomatoes. The failure to find *Salmonella cerro* seven days after its application to growing tomatoes upholds the contention that organisms of fecal origin will not be present in sufficient number to cause gross contamination.

It is felt that tomatoes grown on soils receiving night soil or sewage sludge fertilization would yield fruit which, if eaten raw, would not be likely vectors for the transmission of human bacterial enteric diseases.

201. Muller, Wilhelm. 1949. The Agricultural Use of Sewage. *Wasser und Boden* (Germany), p. 124. Abst:*Sewage and Ind. Wastes* 22:589.

During recent years, the agricultural use of sewage has often been discussed in Germany with no final answer being reached on this important question. Public health requires a hygienic sewage disposal, but local authorities alone cannot solve the problem. It is a task for the State organization, especially in densely settled countries.

Water conservation has become more important and water use must be regulated. Within this water planning, sewage has its own part. In particular, the agricultural use of sewage by different technical means may appreciably increase a country's productivity. For this purpose, sewage must be fully treated and freed of pathogenic organisms.

The humus matter and the manure value of sewage should be used in agriculture to compensate for the organic matter exported from the country as food. Sewage disposal into the ocean only "manures" the sea water. Treated sewage should be discharged into rivers only in such volume as is necessary to manure the rivers for fishing industries.

202. Rawn, A. M. 1934. Salvage of Sewage Studied. *Civil Engr.* 4:471-472.

A report of the Joint Committee of the Sanitary Engineering and Irrigation Division based on questionnaires mailed to Public Health Directors of the 48 States and the District of Columbia to learn the extent of sewage use for irrigation in each of the States, the influence of such use on public health, and the standards that should be prescribed and enforced if water and fertilizer reclaimed from sewage are to be used in the production of foodstuffs to be eaten raw, to be cooked, to be used as fodder crops, or to be used in the irrigation or fertilization of public grounds.

Nine of the forty States responding acknowledged experience with sewage irrigation. Four claimed illnesses could be traced directly to such use; one claimed cattle pastured on raw sewage-irrigated fields developed poorly and were infected with a disease that rendered the meat unfit for human consumption.

Others indicated no difficulty, probably because of the manner of irrigation and the nature of the crops grown. Many of the States without experience indicated that such practice would be prohibited in any form on vegetables or fruits to be eaten raw. The majority expressed a willingness to allow its use on fodder crops or on lawns and parks.

Other results of the survey are also discussed.

203. RAWN, A. M., ET AL. 1942. Salvage of Sewage: Final Report of the Joint Committee of the Sanitary Engineering Division and the Irrigation Division. *Trans. Amer. Soc. Civil Engr.* 107:1652-1687.

This comprehensive report considers the salvage of products from sewage: "Water, fertilizer, gas, grease, and such other materials as may be separated from sewage in the treatment plant or elsewhere and used."

From Public Health considerations, the following are considered important guidelines:

(a) Raw sewage, or its untreated solids content, or the soil which it has recently irrigated shall not come in contact with food-stuff designated for human consumption; nor shall livestock graze upon pasture irrigated therewith;

(b) Forage crops which are to be harvested and cured may be irrigated with the untreated effluent from adequate subsidence tanks.

(c) For use in the cultivation of human foodstuff, particularly that to be eaten raw, the water reclaimed from sewage must be well oxidized and thoroughly sterilized at all times; and

(d) Sewage solids to be used as fertilizer must be digested and dried, or if undigested may be kiln-dried at temperatures which will destroy all inimical pathogenic organisms.

Discussions cover the reclamation and use of water from sewage, both for irrigation and industry, and the reclamation and use of fertilizer from sewage.

A bibliography with 65 entries is included.

204. TANNER, FRED W. 1935. Public Health Significance of Sewage Sludge When Used as a Fertilizer. *Sewage Wks. Jour.* 7:611-617.

The application of sewage sludge to soil on which vegetables, which may be eaten raw, are grown should be practiced with caution. While longevity of pathogenic bacteria in sludge would probably be greatly influenced by the nature of the sludge and the conditions under which it is stored and handled, sufficient data have been recorded to indicate the presence of viable *Bacterium typhosum* cells in sludge. At best, the sludge should be added to the soil in the late fall, winter, or early spring. Wolman's advice, probably sound, is that sludge not be added to growing crops. Sanitary districts and others concerned with the sale of sewage sludge to farmers might well consider the health hazards involved.

205. WRIGHT, C. T. 1950. Pollution of Irrigation Waters. *Sewage and Ind. Wastes* 22:1403-1412.

The report emphasizes the importance of irrigation for the economic and agricultural development of the western states. In this connection, pollution of irrigation waters is a problem that must be solved in some areas to permit maximum utilization of water resources. Opinions differ among health authorities as to the health hazards associated with the use of polluted water for irrigating edible crops. This is reflected in the lack of uniform requirements or standards covering such use. As no widely accepted requirements or standards exist for the quality of irrigation waters or the streams from which they are drawn, there is a definite need for basic data on which reasonable requirements can be based.

No conclusions can be drawn from current studies relating to the pollution of irrigation waters, and health authorities agree that more research is needed to develop methods which will permit full utilization of existing and potential irrigation waters. These studies should include epidemiological investigations to determine the relationship between the use of truck crops exposed to polluted irrigation waters and enteric infections. There appears to be some agreement regarding the use of well-oxidized and adequately disinfected effluents for irrigating fruits and vegetables. In the absence of widely accepted requirements or standards, health authorities must require a high degree of treatment for domestic and industrial wastes where irrigation waters are involved in order to eliminate possible health hazards.

1951 — 1955

206. ANONYMOUS. 1955. Hygiene of Irrigation and the Use of Sewage Residues. *Städtehygiene* 6:259-260. *Water Poll. Abst.* 29:244 (1348).

A draft is given of a proposed standard (DIN 19650) dealing with requirements for water used for irrigation and with the use of sewage and sludge in agriculture.

207. BUTLER, R. G., ORLOB, G. T. and MCGAUHEY, P. H. 1954. Underground Movement of Bacterial and Chemical Pollutants. *Jour Amer. Water Wks. Assn.* 46:97-111.

The movement of bacterial and chemical pollutants via water percolating through the soil above the water table has been studied somewhat more extensively than the travel of pollution via groundwater movement. Emphasizes the need for investigations in both areas. From reports in the literature and the results of field and pilot-scale studies conducted by the University of California Sanitary Engineering Research Laboratories (SERL), several significant conclusions were drawn. These are listed and briefly discussed. A bibliography with 29 entries is included.

208. DUNLOP, S. G., TWEDT, R. M., and WANG, W. L. 1951. *Salmonella* in Irrigation Water. *Sewage and Ind. Wastes* 23:1118-1122.

Salmonella were recovered from a significant proportion of samples of irrigation water contaminated with a primary-treated sewage plant effluent. These same organisms, however, were not recovered from samples of vegetables irrigated with this water. Furrow irrigation was the method of application. Any organisms in the water would have to be splashed onto the leaves and stems above the ground or conveyed to the plant by some other means. Root crops might be expected to be contaminated to a greater extent.

209. Dunlop, Stuart G. 1952. The Irrigation of Truck Crops with Sewage Contaminated Water. *The Sanitarian* 15:107-110. (Nov.-Dec.). *PHE Abst.* 33:S:28.

Evidence is presented that a significant proportion of irrigation water samples, contamined with treated and untreated sewage effluents, contain pathogenic enteric microorganisms. Such organisms, however, were only rarely isolated from the washings of vegetables irrigated with this water. The author points out that it would therefore appear that the health hazard associated with the use of sewage-contamined water for the irrigation of truck crops to be consumed raw is not as great as has been assumed in the past; nevertheless, the fact that the water has been demonstrated to be contaminated indicates that a hazard still exists, and that every effort must be made to provide adequate treatment of all domestic and industrial wastes before discharging into streams to be used later for irrigation purposes.

210. Dunlop, S. G., Twedt, R. M., and Wang, W. L. 1952. Quantitative Estimation of *Salmonella* in Irrigation Water. *Sewage and Ind. Wastes* 24:1015-1020.

A quantitative method was developed for estimating *Salmonella* numbers in sewage-contaminated irrigation water. Of 11 such samples, 8 were positive for *Salmonella*. The median value for the 11 samples was 0.9 per 100 ml. Only 1 to 14 samples of vegetables irrigated with this water was positive for these organisms. Ratios of 225,000 coliforms and 4,800 enterococci to one *Salmonella* were computed from the median values obtained from the water samples.

211. Falkenhain, H. S. 1953. Regulations for Irrigation and the Use of Sewage Sludge. *Wasserw.-Wass. Tech.* 3:293-294. *Water Poll. Abst.* 28:273 (1805).

Proposed German regulations for irrigation and for the use of sewage sludge are discussed. The author considers the divergent views in the literature on the subject of preliminary treatment of sewage and trade waste waters for use in agriculture. Special importance attaches to the destruction of parasitic worms and pathogenic bacteria. During sedimentation the numbers of these are reduced, but the danger of infection is not removed.

212. Harmsen, H. 1955. Hygiene of Land Treatment of Sewage. *Städtehygiene* 6:253-259. *Water Poll. Abst.* 29:244 (1347).

The author discusses the hygienic risks and the precautions necessary in the various methods for disposing of sewage on land and the agricultural utilization of sewage, with special reference to infectious sewage. The conditions required for satisfactory disposal and the effect of these methods and also of methods of sewage treatment in sewage works on pathogenic bacteria are considered.

213. Koziorowski, Bohdan. 1953. Public Health Aspects of Sewage Farming. *Gaz. Woda i Tech. Sanit.* (Polish) 27:100. Abst: *Sewage and Ind. Wastes* 25:1480.

Secondary treatment of the sewage should precede its use in sewage farming, but this is costly and fertilizer value is reduced by 20 percent over that of primary treatment. The spraying of primary effluent on fields and forests is recommended, but produce taken from these fields should be processed properly before consumption.

214. Krey, W. 1954. Agricultural Utilization–Including Application as Artificial Rain–of River Water and Sewage. *Desinfektion* 46:82. *Water Poll. Abst.* 29:28 (162).

The author discusses regulations for the use of sewage and sludge as fertilizer, the hygienic advantages of using surface water, and the possible carriage of disease by sewage. He argues strongly against the use of untreated sewage and emphasizes the need for strict supervision of agricultural use.

215. Kruez, C. A. 1955. Hygienic Evaluation of the Agricultural Utilization of Sewage. *Gesundheits Ing.* 76:206-211. *Water Poll. Abst.* 29:28 (161).

The author discusses the hygienic problems arising from the agricultural utilization of sewage and the amount of agricultural use in the United States, Great Britain, the Soviet Union, and Germany. He considers the dangers to health, precautions necessary in the use of sewage and sludge, the fertilizer and humus-forming effects of sewage and sludge, and the effect of treatment on the fertilizing constituents.

216. Norman, Noah N. and Kabler, Paul W. 1953. Bacteriological Study of Irrigated Vegetables. *Sewage and Ind. Wastes* 25:605-609.

The coliform content of the irrigated soils studied reflects, in general, the coliform density of the waters they receive. Vegetables irrigated with waters of high coliform count exhibit a higher coliform flora than vegetables irrigated with relatively pure water. The coliform density of leafy vegetables irrigated with polluted water is higher than that of smooth vegetables grown under similar conditions.

Under the conditions of this study, the enterococcus indices of soils and vegetables showed no direct relationship to the indices of irrigation waters.

Salmonella were present in the irrigation waters in readily demonstrable numbers, were present in soils in only low concentration, and were insufficiently numerous on the vegetables to be demonstrated by the procedures used.

217. Reinke, E. A. 1951. California Regulates Use of Sewage for Crop Irrigation. *Wastes Engr*. 22:364, 376.

The State Department of Public Health has adopted regulations governing use of sewage for crop irrigation. They prohibit use of raw sewage on growing crops; provide that partially disinfected effluents shall not be used to water growing vegetables, garden truck, berries, or low-growing fruits such that fruit is in contact with the ground; but may be used on nursery stock, cotton, and such field crops as hay, grain, rice, alfalfa, sugar beets, fodder corn, cowbeets, and fodder carrots.

Well-oxidized, nonputrescible and reliably disinfected or filtered effluents, which meet the bacterial standards established for drinking waters, may be used without restriction.

The degree of sewage pollution of irrigation waters varies with the source of supply.

218. Rudolfs, W., Falk, L. L., and Ragotzkie, R. A. 1951. Contamination of Vegetables Grown in Polluted Soil: I. Bacterial Contamination. *Sewage and Ind. Wastes* 23:253-268.

"Field experiments during two growing seasons were designed to evaluate and compare the extent of coliform contamination of tomatoes to those grown in a similar but uncontaminated environment. The pollution consisted of either furrow irrigation with settled sewages normally used for the purpose, or direct application of feces suspensions to the fruit and leaves, which may represent spray types of irrigation on direct application of night soil as frequently practiced. In addition, the survival of pathogenic types, such as *Salmonella* and *Shigella* genera, was investigated to supplement with direct evidence the findings with coliform organisms. The results show that if sewage irrigation or night soil application is stopped one month before harvest, the fruit, if eaten raw, would not be likely vectors for the transmission of human bacterial enteric diseases."

219. Rudolfs, W., Falk, L. L., and Ragotzkie, R. A. 1951. Contamination of Vegetables Grown in Polluted Soil: II. Field and Laboratory Studies on *Endamoeba* Cysts. *Sewage and Ind. Wastes* 23:478-485.

"Laboratory and field experiments on the survival of *Endamoeba histolytica* cysts applied either in suspension or in conjunction with feces to tomatoes and leaf lettuce direct, or to soil in which the plants were growing, show that the cysts are extremely sensitive to desiccation. Addition of organic matter in the form of fecal suspensions does not enhance survival of the cysts. Crops growing in the field may become contaminated directly during the course of irrigation with sewage polluted water or night soil, or indirectly through contact with polluted soil. Contaminated tomatoes and lettuce are free from viable cysts within three days after contamination occurs, the time of decontamination decreasing with a decrease in the degree of wetness of the soil. Field-grown crops consumed raw and subject to contamination with cysts of *E. histolytica* are considered safe in the temperate zone one week after contamination has stopped and after two weeks in wetter tropical regions."

220. Rudolfs, W., Falk, L. L., and Ragotzkie, R. A. 1951. Contamination of Vegetables Grown in Polluted Soil: III. Field Studies on *Ascaris* Eggs. *Sewage and Ind. Wastes* 23:656-660.

"Field experiments on the survival of *Ascaris suum* eggs were conducted by spraying suspensions of *Ascaris* eggs and feces on growing tomatoes and lettuce. Plants and fruits were harvested at intervals. Results show that a reduction of the number of eggs took place with time, but some eggs remained on the plants and fruits for more than a month. Development of eggs was greatly retarded and completely developed eggs containing motile embryos required for infection were not recovered. The exposure of undeveloped eggs to field conditions reduced greatly the viability of the eggs. It appears that resistance of *Ascaris* eggs on vegetable surfaces is less than might be expected from considerations of their resistance in soil, feces, or night soil. All eggs degenerated after 27 to 35 days and were incapable of development for infection."

221. Rudolfs, W., Falk, L. L and Ragotzkie, R. A. 1951. Contamination of Vegetables Grown in Polluted Soil: IV. Bacterial Decontamination. *Sewage and Ind. Wastes* 23:739-751.

"Studies on coliform decontamination of raw tomatoes grown on sewage polluted soils, or sprayed with *E. coli* or feces, show that the natural death rate of these bacteria under ordinary storage conditions is slow and does not insure adequate decontamination. Vigorous washing for 15 min. with plain water removes most of the sprayed-on contaminants, but does not remove coliform from tomatoes grown on polluted soil. In general, vigorous washing with anionic, nonionic, and cationic detergents is not materially better than washing with plain water. Chlorine and its compounds in high concentration in solution do not remove organisms protected by dirt, or in cracks, crevices, or bruises. Chlorine gas is a good decontaminating agent, but causes bleaching in the concentrations required. Nitrogen trichloride and t-butyl hypochlorite are not effective in the concentrations normally used for fruit spoilage control. The most effective method for consistently obtaining a low coliform residual, without affecting the appearance and condition of the vegetables, is soaking them in water at a temperature of 60°C for 5 minutes."

222. Rudolfs, W., Falk, L. L., and Ragotzkie, R. A. 1951. Contamination of Vegetables Grown in Polluted Soil: V. Helminthic Decontamination. *Sewage and Ind. Wastes* 23:853-860.

"Physical and chemical means of decontaminating vegetable surfaces contaminated by *Ascaris suum* eggs included vigorous washing and soaking in plain water, detergent solutions, germicidal rinses, and use of warm water. The results show that the eggs adhere tenaciously to solid surfaces. Various detergents and germicidal rinses were not effective killing agents, but cationic detergents will cause more than 90 percent removal of eggs from smooth surfaces, such as tomatoes. The removal is less effective when cracks, crevices, or bruises protect the eggs. The only effective method to insure vegetable decontamination with respect to helminth eggs is immersion of the vegetable in warm water (55° to 60°C) for 10 minutes. Such immersion does not alter the appearance or character of the vegetables tested."

223. RUDOLFS, W., FALK, L. L., and RAGOTZKIE, R. A. 1951. Contamination of Vegetables Grown in Polluted Soil: VI. Application of Results. *Sewage and Ind. Wastes* 23:992-1000.

The authors state the following general conclusions:

1. No evidence has been found that pollutional bacteria, amoeba, or helminth eggs penetrate healthy, unbroken surfaces of vegetables or cause internal contamination.

2. Vegetables to be eaten raw can be grown without health hazard in soils subjected to sewage irrigation, night soil application, or polluted stream water irrigation in years prior to the season in which the vegetables are grown.

3. Vegetables grown under conditions of surface sewage irrigation show no higher coliform concentrations than those grown on normally farmed soil, whether sewage was applied before the plants were set or while the plants were growing.

4. If sewage sludges or night soil are applied on the soil surface, or sewage effluents are applied by overhead irrigation during growth of vegetables, applications should be stopped at least one month before harvest. If this precaution is taken, the crop will show no higher bacterial contamination than when farmyard manure or artificial fertilizers are applied.

5. Strains of *Salmonella* and *Shigella* do not survive on vegetable surfaces for more than one week. Hence, conclusions based upon coliform contamination offer a considerable margin of safety.

6. Bacteria applied to vegetable surfaces are tenaciously held and protected from the external environment. This permits their survival under field conditions and explains the difficulty of their removal by various types of washes or kill by germicides.

7. The resistance of cysts of *Endamoeba histolytica* to the external environment depends almost entirely on the amount of moisture present. Death of the cysts occurs immediately upon desiccation.

8. During dry periods, cysts of *E. histolytica* survive less than 3 days on vegetables growing above ground in the field. To reduce to a minimum the danger of transmitting amoebic dysentery through crop contamination, the last application of contaminating material to the soil before harvest should be at least one week in the temperate zone and two weeks in the wetter climates of tropical regions.

9. Eggs of *Ascaris suum* were recovered in reduced numbers from vegetables one month after application, but all had degenerated, and no completely developed eggs were found on plants in the field. The possible dangers of the transmission of *Ascaris* are greatly reduced if fecal matter fertilization is stopped one month before harvest.

10. Storage, washing of vegetables in plain water, or washing with

various detergents, including anionic, nonionic, and cationic compounds, are ineffective as means of bacteriological decontamination.

11. Germicidal rinses of chlorine and its compounds are superior to water and detergents for bacterial decontamination, but are unreliable.

12. Water, anionic, most nonionic detergents, and chlorinated compounds are not effective decontaminants for helminth eggs; cationic detergents aid in removal of eggs from vegetable surfaces. The eggs are resistant to the killing effects of disinfectants which could be used in vegetable decontamination.

13. The only reliable method for decontamination of bacterial, amoebic, and helminthic organisms is pasteurization at 60° C for 5 minutes.

224. SNYDER, CHARLES W. 1951. Effects of Sewage on Cattle and Garbage on Hogs. *Sewage and Ind. Wastes* 23:1235-1242.

In making use of sewage effluents, the degree of treatment required must be governed by its subsequent reuse if the greatest social and economic advantages are to be realized. Since there are many diseases common to both man and animals, the possibility of disease transmission by sewage must not be overlooked.

Experiments are cited in which swine were fed with incoming sewage mixed with bran; others were fed with effluent mixed with bran. Careful post-mortem examinations revealed no evidence of disease. Cows were supplied with effluent for drinking. Likewise, no evidence of disease was found. It was concluded that virulent bacteria were not present in sufficient concentration in the sludge and effluent of the treatment plant at Beltsville to cause disease in susceptible animals.

The feeding of raw garbage to hogs can lead to trichinosis in the animals and transfer to man if the meat is not properly cooked. Garbage can be cooked to destroy the infection before feeding to the animals.

225. WANG, WEN-LAN LOU and DUNLOP, S. G. 1954. Animal Parasites in Sewage and Irrigation Water. *Sewage and Ind. Wastes* 26:1020-1032.

An investigation was made to determine the efficiency of primary sewage treatment plus chlorination, as practiced in the Denver sewage disposal plant, on the removal of animal parasites. The results indicated that about 20 percent of the *Ascaris* ova and 46 percent of the *End. coli* cysts found in the raw sewage were still present in the final effluent. However, the sewage treatment showed a removal of over 99 percent of the coliform and enterococci.

When the effluent joined the South Platte River and the flow reached Gardeners' irrigation ditch, the number of *Ascaris* ova and *End. coli* cysts was found to be reduced considerably. The coliform organisms and enterococci, on the other hand, showed a higher incidence in this ditch than in the effluent.

Definite conclusions concerning the public health significance of these findings cannot be stated since little is known of the minimum infecting doses of these organisms.

226. WARRINGTON, SAM L. 1952. Effects of Using Lagooned Sewage Effluent on Farmland. *Sewage and Ind. Wastes* 24:1243-1247.

From a public health standpoint, the degree of treatment and the types of crops grown should be of utmost importance. Where complete treatment is not practiced, the use of the effluent and crops grown should be carefully controlled. Crops which do not come in contact with the water may be grown with comparative safety. In areas where salt naturally tends to build up, the water should be used with caution. Its salt content, particularly chlorides, should be checked often. The fertilizing value of sewage effluent is great, and when it can be used, the process can convert a liability into an asset.

227. WEILAND, K. 1955. Development and Present Condition of Sewage Treatment and Utilization in Berlin. *Wasserw.-Wass. Techn.* 5:229. *Water Poll. Abst.* 29:347 (1897).

A detailed description is given of the historical development and operation of the Berlin irrigation fields and of the construction and design of the Stahnsdorf and Wassmannsdorf sewage works. The author then discusses the hygiene of agricultural utilization of sewage, the principles of operation, and the necessary precautions and conditions.

228. WIERZBICKI, JAN. 1952. Sewage Disposal by Land Irrigation. *Gaz. Woda i Tech. Sanit.* (Polish) 26:34. Abst: *Sewage and Ind. Wastes* 24:1554.

A description is given of a land irrigation system in Lower Silesia, which was built in 1906 and has continued in operation to the present time. Data are presented on soil variation with depth in irrigated and nonirrigated soils as well as the humus, P_2O_5 and K_2O contents, and pH changes. Various vegetables are grown, but are not irrigated during the growing season. Workers employed in the fields for over 30 years have had no illnesses or disease outbreaks that could be attributed to the agricultural utilization of sewage wastes.

1956 — 1960

229. BERGER, B. B. 1960. Public Health Aspects of Water Reuse for Potable Supply. *Jour. Amer. Water Wks. Assn.* 52:599-606.

The author discusses the feasibility of treating sewage so that the reclaimed water may serve all municipal purposes, including water for drinking. The recent reuse experiences of Chanute and Lyndon, Kansas, are described. It was concluded that modern sewage treatment processes are designed to produce an effluent that will be easily assimilated by the receiving body of water, and that they are not intended to produce a water suitable for a municipal water supply.

230. Harmsen, H. 1957. Irrigation and Utilization of Sewage Residues (Hygienic Regulations). *Städtehygiene* 8:25-27. *Water Poll. Abst.* 30:385 (2182).

In view of the objections raised, especially from a hygienic point of view, to the provisions of DIN 19650 issued in 1956 and dealing with irrigation and the use of sewage, the author surveys work done and legal enactments on the hygienic problems of use of sewage on land.

231. Herzik, G. R., Jr. 1956. Texas Approves Irrigation of Animal Crops with Sewage Plant Effluents. *Wastes Engr.* 27:418-421.

The author reviews the findings of Willem Rudolfs et al. of Rutgers, concerning the growing of vegetables in polluted soil. Also refers to other work relative to bacteria and virus infections of raw vegetables.

In June 1952, the Texas Board of Health approved a resolution defining its stand on this matter as follows:

> "The use of raw or partially treated sewage or the effluent from a sewage treatment plant is prohibited for use as irrigation water on any food crop which might be consumed in the raw state. Such practice is the deliberate exposure of food to filth as defined by Art. 707 of our Texas Penal Code."

Outlines the point of view of the State Department of Health regarding the public health aspects of sewage irrigation as follows:

1. Do not favor use of raw sewage for irrigation regardless of type of crop. Sewage effluent receiving at least primary treatment may be used for irrigation, but not for crops for human consumption. Encourages use of primary treated, and preferably completely treated, sewage on feed and pasture crops used for animal consumption or as an adjunct to soil conservation practices.

2. The practice should be followed in such a way as to prevent the creation of a public health hazard, nuisance, or stream pollution.

3. If handled properly, the sewage used at an irrigation farm should not be hazardous to the operators.

4. Sewage sludge has certain soil conditioning and fertilizing characteristics. It likewise is not recommended for use on crops for human consumption.

5. Sewage irrigation makes use of water that is usually wasted, aids the area economy, reduces pollutional loads on streams, and is not hazardous to the operators. From these considerations, its continued favorable consideration is heartily endorsed.

232. Jey, B. N., Agadzhanov, R. A., Allakhverdyants, S. A., Dashkova, E. M., Maiorova, L. A., and Shtok, E. S. 1960. The Results of Sanitary and Hygienic Investigations of ASHKHABAD Sewage Farms. *Gigiena i Sanitariya* No. 12, 18-20. *PHE Abst.* 41:S:41.

It was found that irrigation of farm fields with sewage from Ashkhabad City produced heavy contamination of the soil. The processes of mineralization and natural soil purification during the 3-6 day interval between applications could not cope with the amount of organic waste introduced into the soil.

Vegetables grown on the farms, especially those in contact with the irrigated soil, were contaminated with *Esch. Coli* and eggs of helminths. In contrast to other parts of the USSR, in these regions the eggs of helminths are found in water, soil, and on vegetables only during autumn and spring months.

233. Muller, G. 1957. Infection of Vegetables by Application of Domestic Sewage as Artificial Rain. *Städtehygiene* 8:30-32. *Water Poll. Abst.* 30:385 (2184).

The author describes experiments in which plots of land, on which carrots, cabbages, potatoes, and gooseberry bushes were growing, were watered with settled sewage. The soil, vegetables, and fruits were tested for the presence of *Bact. coli* and *Salmonella* at intervals up to 40 days after application of sewage. The amounts of sewage used were small, but *Salmonella* were detected in the soil and on the potato tubers after 40 days, on carrots after 10 days, and on cabbage leaves and gooseberries after 5 days.

234. Reploh, H. and Handloser, M. 1957. Investigations on the Spread of Bacteria Caused by Irrigation with Waste Water. *Arch. Hyg.* (Berlin) 141:632-644. *PHE Abst.* 39:S:54.

High values for the spread of bacteria as given in the literature cannot be obtained when the present customary types of sprinkling equipment are employed. But it has to be assumed that, at high wind velocity, very small droplets containing bacteria are spread considerably beyond the proper zone of action. When the use of sprinkling equipment is projected, this must be taken into consideration and strips of land of sufficient size provided for protection from the spread by wind. Probably, the zone spread can be safely lessened by planting hedges for protection from the wind.

1961 — 1965

235. Babov, D. M. 1962. Bacterial Contamination of Soil and Vegetables on Fields After Seasonal Sewage Irrigation in the Southern Ukraine. *Gigiena i Sanitariya* No. 11, 37-41. *PHE Abst.* 43:112.

The investigation showed that the use of sewage for irrigating agricultural fields in the Southern Ukraine is accompanied by contamination of soil and vegetables with intestinal bacteria. However, as the result of energetic self-purification processes, the ripe vegetables harvested from these fields do not differ in level of bacterial contamination from those in the market. In case of serious infringements of the irrigation regimen and of the time fixed for cessation of irrigation before harvest, live pathogenic bacteria may be found on vegetables. An almost complete absence of intestinal bacteria on corn silage points to the advantages of agricultural sewage irrigation of fields for the growing of corn.

236. Dunlop, Stuart G. and Wang, Wen-Lan Lou. 1961. Studies on the Use of Sewage Effluent for Irrigation for Truck Crops. *Jour. Milk and Food Tech.* 24:44-47.

The authors report on studies which were designed to assess the public health hazards associated with the use of sewage effluent for irrigation under field conditions. These studies concluded that no significant contamination results from the use of chlorinated effluent diluted in streams and subsequently used in furrow irrigation.

237. Lehmann, A. F. 1965. Why Sewage Effluents Must be Chlorinated. *Amer. City* Vol. 80, July, p. 79-81.

Growing water reuse and increased recreational requirements on our streams and reservoirs are making effluent chlorination not only desirable but imperative in more and more areas.

Microbiologists agree that secondary treatment reduces the number of pathogenic organisms in waste water, but they also recognize the need for chlorination to reduce them "below demonstrable levels." Unchlorinated raw or settled waste water constitutes a health hazard when discharged to bodies of water with which people may come in contact. Secondary treatment reduces but does not eliminate the risk.

Costs are not prohibitive. Estimates based on observed practices are given.

238. Shuval, Hillel I. 1962. Public Health Aspects of Waste Water Utilization in Israel. *Proc. 17th Ind. Waste Conf.,* Purdue Univ. 112:650-665.

It is estimated that total water reserves in Israel can be increased by at least 10 percent through waste water reclamation programs. Early efforts were devoted to direct agricultural irrigation with treated sewage effluent. Some 50 projects of this type are in operation. Results have been good, and there has been no indication of any resulting menace to the public health. However, due to restrictions by the Ministry of Health as to the types of crops that can be irrigated and other engineering and health considerations, more recent efforts are being directed toward groundwater recharge with treated waste water. A major groundwater recharge project in the Dan Region is described.

5

Industrial, Recreational, and Other Water Reuse Applications

Although agricultural utilization of waste water was the major area considered in preparing this bibliography, other important reuse applications should not be overlooked. Innumerable examples of water reuse by industry can be found in the literature. A few significant reports are included to provide the reader a basis for further review.

There are two important considerations in the industrial use of waste water. In general, industry requires a fairly constant supply of water; at the same time it consumes only a small portion of the water it uses. Waste water such as sewage effluent is generally available on a continuous basis. It is thus possible for an industry to arrange a mutually satisfactory agreement with a city for the supply of uniformly large quantities of waste water. Since only a small portion of the water supply is consumed, water used for cooling, various washing operations, or even for the conveyance of materials can often be recycled with little treatment and reused many times over. The factors which influence industry to make use of waste water are largely economical. For instance, sewage effluent may be the cheapest water source available, especially if its quality is such that little additional treatment is required.

Water quality requirements of an industrial water supply are dependent upon the intended use of the water, and may differ considerably from those for municipal or agricultural uses. In many cases, a high mineral content water or one which does not meet bacteriological drinking water standards may be used. In such cases, with industry utilizing reclaimed waste water of poor quality, it is then possible to apportion the higher quality waters in greater volume to other beneficial purposes.

Another valuable water reuse application, which is covered extensively in the literature, is for recreational purposes. Under this heading are grouped such uses as irrigation of parks, golf courses, and other public property; maintaining the desired levels in small, decorative lakes in parks or golf courses; and water supply for fish-breeding ponds and/or wildlife areas. Modern technology makes it possible to produce a dependable supply of effluent for such uses with a minimum of health and aesthetic problems. Significant financial advantage can often be realized by a city when its sewage effluent is utilized as an alternate water source on recreational areas instead of the normal municipal supply. The practice conserves available potable water for other uses.

The quality requirements of a waste water are not as critical for recreational irrigation as for general agricultural irrigation. Many grasses, shrubs, and trees are much more tolerant to sodium and salinity hazards than are many agricultural crops. The beneficial fertilizer elements in reclaimed effluents are an important consideration in park and golf course irrigation, and the value of the organic content as a soil-conditioning agent may be even more important than the nutrient content. As with other agricultural applications, it is desirable to prevent the introduction of highly mineralized industrial wastes into the sewerage system if the effluent is to be reclaimed for irrigation. Many reports in the literature indicate that reclaimed waste water is superior to potable water supplies for growth and maintenance of vegetation.

Reclaimed waste water has been reported to be a practical and feasible method to recharge groundwater aquifers. Recharge can be accomplished in several ways. Injection wells and spreading basins have been employed. In coastal areas, planned recharge has been used to create a freshwater barrier against the intrusion of saline water into overdrawn aquifers. Other recharge may be simply to replenish the underground reservoir. Some recharge occurs incidental to agricultural irrigation, especially where excessive water is applied. Increased demand and rising water costs in the future may greatly enhance the popularity of recharge operations; underground aquifers are nature's best storage reservoirs.

One other reuse application is that of potable water supply. A city seldom recycles its own effluent, although cases are on record where this has been done due to necessity. Consider, however, the city which takes its supply from a river that contains the effluent of upstream neighbors. Modern treatment methods can produce an effluent which meets the bacteriological standards for drinking water. Better effluent from increasingly effective treatment plants will dilute river water and its quality may be improved. Further emphasis on pollution control should serve to greatly improve the quality of our river waters over some that are presently referred to as "open sewers."

Abstracts Prior to 1951

239. McQueen, Frank. 1934. Sewage Treatment for Obtaining Park Irrigating Water. *Pub. Wks.* 64:16-17. Abst: *Sewage Wks. Jour.* 6:145-146.

Golden Gate Park (1,013 acres), San Francisco, was originally irrigated with sewage from an outfall sewer traversing the park. This was soon discontinued because of objectionable odors. The purchase of potable water proved too costly. A new sewage treatment plant, completed in 1932 and employing the activated-sludge process, supplies 1 mgd for irrigation of the Park. The water is clear, odorless, and completely satisfactory for the purpose. Odors and suspended matter are so completely removed that the excess plant effluent is used for lakes and waterfalls.

240. Rawn, A. M. 1950. Blending of Sewage Effluent with Natural Waters Permits Reuse. *Civil Engr.* 20:324-325, 373.

Reclaiming water from sewage is not a new idea; the reuse of sewage or effluent for agriculture, industry, and other purposes has been well established.

Water reclamation from sewage depends on sound engineering principles. Public acceptance of unrestricted reuse of sewage waters often depends on the inclusion of a "natural" purification process, such as blending with lake, river, or underground waters.

1951 — 1955

241. Hathaway, Gail A. 1954. Water—A Critical Material. *Civil Engr.* 24:534-536. *PHE Abst.* 34:W:64

The author predicts that water requirements in the nation may double by 1975. The two highest priorities for water use are recognized as human and animal consumption. Priorities for irrigation, recreation, power, navigation, etc., are in conflict due to divergent interests. Changing interests and economic pressures may influence the operating policy of a water resource project.

Future water problems must be solved by recirculation, reclamation of used water, regulation of streams, development of new groundwater storage, reduction of transpiration losses by elimination of heavy water-using vegetation, and possibly removal of salt from sea water. A sound national policy and coordinated efforts will be required if future water problems are to be solved.

242. Hoak, R. D. 1953. Water Use and Conservation Policy. *Chem. Engr. News* 31:3448-3454. Abst: *Sewage and Ind. Wastes* 26:1056.

The article is a synopsis of a symposium on "Water Use and Conservation Policy" held in Los Angeles in April 1953. It discusses the difficulties of developing a sound policy; a survey of the water resources of various regions; economics of land reclamation; flood control; hydroelectric power; recreation; pollution control; water reuse in industry; and irrigation water.

243. Keating, R. J., and Calise, V. J. 1955. Treatment of Sewage Plant Effluent for Industrial Re-Use. *Sewage and Ind. Wastes* 27:773-782.

One practical and substantial source for additional industrial water supplies is the effluent from municipal sewage treatment plants. The author discusses current developments and factors involved in the design of equipment for treatment of sewage plant effluents for reuse in industrial processes and boiler feed applications.

244. Martin, Benn. 1951. Sewage Reclamation at Golden Gate Park. *Sewage and Ind. Wastes* 23:319-320.

The processes employed in the sewage treatment plant in San Francisco's Golden Gate Park are described. The plant has a design capacity of 1 mgd, and produces effluent at a cost of 7¢ per 1,000 gal. Chlorination is carefully controlled and the final effluent meets drinking water standards. The effluent is used for irrigation and to maintain the level of Stow Lake, where a boating concession operates.

1956 — 1960

245. Anonymous. 1957. Industry Utilizes Sewage and Wastes Effluents for Processing Operations. *Wastes Engr.* 28:444-448.

This article discusses industrial use of sewage and wastes effluents. Several examples of reuse are cited.

246. Connell, C. H. 1957. Utilization of Waste Waters. *Ind. Wastes* 2:148-151. *PHE Abst.* 38:S:50.

In Texas, indirect reuse of water can seldom be practiced because few streams have sufficient flow to dilute and purify a plant effluent and carry it to a downstream water intake. Texas uses more sewage effluents for cooling and boiler makeup water than any other state. The total use of these waters in Texas is less than 4 mgd, or about one-half the total amount of such waters used in the U. S. The big users of sewage effluents are the Cosden Petroleum Corporation of Big Spring, Texas, and the Texas Company of Amarillo, Texas.

247. Connell, C. H., and Berg, E. J. M. 1959. Industrial Utilization of Municipal Wastewater. *Sewage and Ind. Wastes* 31:212-220.

Industrial use of municipal wastewater constitutes approximately one percent of the total available. The potential use may be as high as 25 percent.

Experience, to date, indicates that municipal wastewater can and should be given more consideration as a source of industrial water supply. This may lead to increased use, especially in areas where competition for water is increasing. Nineteen industrial plants are listed that now use municipal wastewater supply. No adverse health effects have been observed in such usage.

248. Derby, Ray L. 1957. Water Use in Industry. *Jour. Irr. and Drainage Div.,* Amer. Soc. Civ. Engr. 83:IR2, 1364, pp. 1-9.

This article briefly discusses the three major considerations of industrial water use: quantity, quality, and reuse. A listing of the average water use in some typical industries is presented. Methods of water treatment are divided into seven classes, and water quality requirements for various industries are given. The savings in cost and in water quantity requirements brought about by the reuse of water are considered.

249. Gloyna, E. F., Drynan, W. R., and Hermann, E. R. 1959. Water Reuse in Texas. *Jour. Amer. Water Works Assn.* 51:768-780.

The possible reuse of wastewater throughout the eastern one-third of Texas was investigated. The factors studied were: (a) wastewater quantity, (b) criteria of quality, (c) needs and cost of reclamation, (d) effects of public opinion on such reuse, and (e) administration of the reuse program. Numerous data were collected, calculations made, and the results presented in tabulations and graphs.

250. Guymon, Boyd E. 1957. Sewage Salinity Prevents Use of Effluent for Golf Course Irrigation. *Wastes Engr.* 28:80-83. *PHE Abst.* 37:S:69.

The salinity of the treated sewage of the city of Coronado, California, was found to be too high to permit its use for irrigating a proposed 18-hole public golf course on land bordering San Diego Bay. The annual cost of irrigating the tract with the municipal supply was estimated to be $26,000. The author presents salinity data for both the public water supply and the sewage, covering a typical 24-hour day. A method of separating the merging flows of two main outfall sewers, one high in salinity and the other acceptable, is illustrated and briefly explained.

251. McGauhey, P. H. 1957. The Why and How of Sewage Effluent Reclamation. *Water and Sewage Wks.* 104:265-270. *Water Poll. Abst.* 30:422 (2394).

The author discusses the need for sewage reclamation in California and the amount of water available from sewage. The total volume of water which could be reclaimed would be only 8 percent of that required for crop irrigation but would be of more value for industry and irrigation purposes in towns. Sewage effluent can be used to recharge groundwater supplies by spreading on the soil. The bacteria present are removed during the first four feet of travel through the soil. Groundwater may also be recharged by direct injection of effluent into water-bearing strata. Bacteria do not travel more than 100 feet in moving groundwater. The author considers the present use of effluents and suggests methods of increasing future use.

252. MERZ, ROBERT C. 1956. Direct Utilization of Waste Waters. *Proc. 11th Ind. Waste Conf., Purdue Univ.,* 91:541-551. *Water and Sewage Wks.* 103:417-423.

A survey shows that more than 150 industries in 38 states reclaim industrial wastes, and about 15 in 9 states employ sewage effluent. The primary reason is that there are significant savings. Specific examples are cited.

Land and climate are the primary factors affecting agricultural utilization of waste water. Several successful operations are described. Restrictions are the amount of water to be disposed of, quality of the effluent, and health regulations.

Other direct utilization is employed for recreational areas (golf courses, decorative lakes, parks, etc.) and groundwater recharge. The author states: "The investigations made thus far indicate strongly that the reclamation of sewage effluents is a sound practice for industry, agriculture, and other uses."

253. MERZ, ROBERT C. 1959. Waste Water Reclamation for Golf Course Irrigation. *Jour. San. Eng. Div.,* Amer. Soc. Civ. Engr. 85:SA6, 1, 79-85.

Three years' experience at municipal and military golf courses shows that reclaimed wastewater can be properly used for irrigation purposes. Value is derived from the fertilizing constituents. Difficulties may arise in certain soils due to increased sodium content of the water. Chlorination will prevent odor nuisance as well as the spread of *B. coli* through wind action.

254. METZLER, DWIGHT F., CULP, R. L., STOLTENBERG, H. A., WOODWARD, R. L., WALTON, G., CHANG, S. L., CLARKE, N. A., PALMER, C. M., and MIDDLETON, F. M. 1958. Emergency Use of Reclaimed Water for Potable Supply at Chanute, Kansas. *Jour. Amer. Water Wks. Assn.* 50:1021-1060.

In 1956-57, during the most severe drought in Kansas history, the city of Chanute, on a temporary emergency basis, recirculated treated sewage effluent through a stabilization pond, the water treatment plant, and the water distribution system. One complete cycle required about 20 days. The authors describe in detail the effects of this reuse on the chemical content, taste, color, and odor of the water. This reuse lasted for five months, and indications were that it could have been continued for another two weeks. The resulting water was safe to drink, but the reuse of sewage treatment effluent to supplement deficient water supplies should be considered or permitted only under the most severe emergency conditions. A discussion of the results of the Chanute water reuse by C. H. Connell is included.

255. MORRIS, SAMUEL B. 1958. Resolving Conflicting Demands for Water. *Jour. Irr. and Drainage Div.*, Amer. Soc. Civil Engr. 84:IR1, 1501, pp. 1-8.

The author discusses some of the problems caused by conflicting demands for water especially in water-short areas. Some of the types of conflicts are considered. The discussion deals especially with irrigation usage and the competition between this and other uses.

256. ONGERTH, HENRY J., and HARMON, JUDSON A. 1959. Sanitary Engineering Appraisal of Waste Water Reuse. *Jour. Amer. Water Wks. Assn.* 51:647-658.

This article briefly summarizes the historical development of waste water reclamation and describes ways in which waste water may be utilized. The engineering, public health, economic, legal, and aesthetic problems encountered in waste water reclamation are discussed.

257. POWELL, SHEPPARD T. 1956. Adaptation of Treated Sewage for Industrial Use. *Ind. and Engr. Chem.* 48:2168-2171.

The treatment of liquid wastes for further use has passed the experimental stage and offers a practical solution for many industrial water problems.

Intelligent appraisal and engineering principles can solve the problems of collection, treatment, and reuse of sewage. The value of this type of water conservation should be publicized at both local and national levels, especially with regard to its adaptability and means for processing.

The California State Water Pollution Control Board has stated:

> "There appears to be no physical reason for treating waste water as being fundamentally different from any other water source. The uses to which it can be put are the same, and the precautions taken before using it are the same."

258. RAWN, A. M. and BOWERMAN, F. R. 1956. Sewage–A Raw Water Supply. *Water and Sewage Wks.* 103:463-467.

The authors recommend planned water reclamation from sewage by establishing water treatment plants. Several historical examples are cited: Grand Canyon, Arizona, Golden Gate Park, and Baltimore.

Design factors are discussed, and comparative costs are given.

259. SCHAD, THEODORE M. 1960. Activities of the Senate Select Committee on National Water Resources. *Jour. Amer. Water Wks. Assn.* 52:965-969.

The author discusses a Senate committee assigned to forecast water needs and water supplies of the future. Projections are being assembled on a regional basis. The committee will probably indicate the nature and extent of development required for each river basin and recommend legislative policy. According to the author, the only practical answer to future water needs is to use the available water over and over again.

260. SCHERER, CLARENCE H. 1959. Sewage Plant Effluent is Cheaper than City Water. *Wastes Engr.* 30:124-127.

The author gives the history of the agreement by which Amarillo supplies sewage plant effluent meeting certain specifications to the Texaco refinery. Of particular interest is the Texas Company's decision to reuse wastewater so as to preserve the ground water for future use by a progressive community.

261. SCHERER, C. H. and ALEXANDER, D. D. 1959. Wastewater Transformation at Amarillo. *Sewage and Ind. Wastes* 31:1103-1108.

Municipal waste water is transformed into a source of industrial water and sold to a petroleum refinery. Experience indicates there is nothing in the effluent from a well-operated activated sludge plant that would preclude its use as an industrial water.

262. SLOAN, GARRETT. 1960. Waste Water Reclamation for Golf Course Irrigation. Discussion. *Jour. San. Eng. Div.,* Amer. Soc. Civil Engr. 86:SA3, 1, 167-168.

Discussion of Merz's (1959) report: Describes the use of effluent from the 0.5 mgd Virginia Keys activated sludge plant at Miami, Florida. Before being applied to a golf course, the effluent is treated by rapid sand filtration, then diluted with city water to reduce chloride content from 1300 to below 900 mg/1.

263. STONE, RALPH. 1960. Waste Water Reclamation for Golf Course Irrigation. Discussion. *Jour. San. Eng. Div.,* Amer. Soc. Civil Engr. 86:SA2, 1, 125-126.

Discussion of Merz's (1959) report: Emphasizes the need of long-time storage of the chlorinated effluent, improving disinfection through prolonged contact time; the fertilizing value due to nitrogen, phosphorous, and potassium content; and proper engineering planning to prevent chloride and boron poisoning of the soil. Warns against excess chlorination leading to corrosion problems, over-irrigation, and difficulties with clay soils.

Automatic sprinkling in early morning hours is preferred.

1961 — 1965

264. ANONYMOUS. 1961. Sewage Reclamation Studies for University City. *Jour. San. Engr. Div.,* Amer. Soc. Civil Engr. 87:SA4, 2, p. 5.

University City is being planned in Orange County, California, as a community of 100,000 population, with a new 1,000-acre campus for the University of California. Reclaimed sewage flow of 10 mgd will be used to irrigate agricultural lands, recreational parks, golf courses, and the campus grounds. Chemical flocculation, sand filtration, and chlorination will supplement primary and secondary treatment for that effluent which goes into artificial lakes to be used for recreational purposes.

265. BAUER, J. H. 1961. Air Force Academy Sewage Treatment Plant Designed for Effluent Reuse. *Public Works* Vol. 92, No. 6, p. 120-122.

Because of limited rainfall and the planned landscaping of the site, the need for a large amount of irrigation water was foreseen. It was planned to utilize the sewage plant effluent to meet this need. Only the excess effluent was to be released to the creek.

Engineering design data and operating results are given.

266. BONDERSON, PAUL R. 1964. Quality Aspects of Waste Water Reclamation. *Jour. San. Engr. Div.,* Amer. Soc. Civ. Engr. 90:SA5, 1, pp. 1-8.

The author examines the effects of reclamation projects on the water resources of an area. The subjects considered are: (1) trends in waste water reclamation, (2) modes of augmenting water resources by such reclamation, and (3) quality aspects associated with such augmentation.

267. BUNCH, ROBERT L. and ETTINGER, M. B. 1964. Water Quality Depreciation by Municipal Use. *Jour. WPCF* 36:1411-1414.

Future reuse of sewage effluents will not be a question of economics, but one of necessity. By 1980, 75 percent of the population will reside in metropolitan areas, and six-time reuse can be anticipated. The study provides information on the organic and inorganic load contributed by one cycle for five cities. The analytical data are tabulated. Generalizations are unwise without considering the loading on the specific treatment plant and the contributions of industrial wastes. Orders of magnitude are indicated that would be helpful in making rough calculations for planning wastewater utilization.

268. CANNON, DANIEL W. 1964. Industrial Reuse of Water: An Opportunity for the West. *Water and Sewage Wks.* 111:250-254.

The author discusses the reuse of water within the petroleum and steel industries. He briefly refers to industrial use of water which has been previously used for municipal purposes; to agricultural use of water previously used for industrial purposes; and to municipal use of water previously used for industrial purposes.

269. CECIL, LAWRENCE K. 1964. Sewage Treatment Plant Effluent for Water Reuse. *Water and Sewage Wks.* 111:421-423. *PHE Abst.* 45:112.

The cost of sewage treatment may be partially recovered by selling the treated effluent to industry for reuse. The merit of this practice will depend on how well the effluent quality meets the needs of the prospective user as well as how it compares with other sources of water.

Additional treatment processes may be necessary to reduce concentrations of undesirable components such as ammonia, phosphates, calcium, and foam-producing organic compounds. The extent of additional treatment is limited by cost and is practical only where overall cost is less than that for an alternate source.

Refineries at Duncan and Enid, Oklahoma, and a zinc smelter in a desert area found that effluents from nearby sewage treatment plants provided a better and less variable quality of water than was available from other sources.

270. Connell, C. H. and Forbes, M. C. 1964. Once-Used Municipal Water as Industrial Supply: In Retrospect and Prospect. *Water and Sewage Treatment* 3:397-400.

The authors state that the total amount of used municipal water is approaching 20 bgd and that over 40 percent of it may in time be used for industrial water. In reviewing direct industrial utilization of sewage effluents, the authors briefly discuss the availability and costs relevant to water quality.

271. Eliassen, Rolf, Wyckoff, Bruce M. and Tonkin, Charles D. 1965. Ion Exchange for Reclamation of Reusable Supplies. *Jour. Amer. Water Wks. Assn.* 57:1113-1122.

The authors describe experimental studies on the removal of phosphates and nitrates from sewage plant effluents by an ion-exchange process. The laboratory work was performed at Stanford University, and the pilot plant work was done in cooperation with the city of Palo Alto, California. The work included an economic study of the ion-exchange process. The removal of phosphates and nitrates is desirable to prevent the growth of algae and to permit maximum reuse of this large potential water resource.

272. Fleming, Rodney R. 1963. Water Reuse by Design. *The Amer. City* 78:106-108.

The author reviews the reuse of sewage effluents as practiced in the United States. Large quantities are reclaimed for both industrial and agricultural reuse. Other reuse includes groundwater recharge to prevent salt water intrusion. Over 200 municipal plants in Texas supply effluent for irrigation. Several Arizona and New Mexico cities water golf courses and parks with sewage effluent. Other examples of reuse are cited.

273. Marks, R. H. 1963. Waste Water Reclamation: A Practical Approach for Many Water-Short Areas. *Power* 107:47-50 (Nov. 1963).

The author describes the operation of a water reclamation plant at Whittier Narrows in Los Angeles County. The system of treatment and the equipment used are discussed and illustrated. At present, this water is used to recharge ground water supplies, but the plant could furnish water for other uses if necessary. Such a treatment plant could be used in other areas for recharge, irrigation, and industrial water supplies.

274. Merrell, J. C., Jr., Katko, Albert, and Pintler, H. E. 1965. The Santee Recreation Project, Santee, California. Summary Report, 1962-1964. *PHS Publ. No. 999-WP-27.*

This paper presents the results of a study of the Santee, California recreational lakes. These lakes were deliberately planned to utilize the community's reclaimed sewage effluent. The seven-agency cooperative study evaluated the fate of viruses along with total and fecal coliform and fecal streptococci through the conventional secondary treatment process, the tertiary processes, and the recreational lakes. The correlating physical and chemical data are presented along with a biological study of the lakes and related land area. Discussions of eutrophication, vector control, epidemiology, and the social acceptance and ecology of the entire recreational park are developed. The study concludes that the treatment provided by intermittent sand filtration has met the nutrient requirements of the emerging ecology and that no health hazards have been demonstrated by the viral or other findings for the present recreational uses of boating and fishing.

275. MIDDLETON, F. M. 1964. Advanced Treatment of Waste Waters for Reuse. *Water and Sewage Wks.* 111:401-410.

Some examples of waste water reuse and the need for advanced waste treatment processes are briefly discussed. The status of advanced waste treatment processes is reviewed by presenting nine process descriptions which represent progress reports of studies in this area. No firm cost figures for these processes could be given; however, estimated costs are made based on projections of data at hand.

276. PARKHURST, JOHN D. 1965. Progress in Waste Water Reuse in Southern California. *ASCE Proc. Jour. Irr. and Drainage Div.* 91: IR1:79-91.

The author emphasizes the extensive planning behind Los Angeles County's current water reuse operation. Waste water reclamation falls into two categories: (1) that which is incidental to water pollution control in inland areas; and (2) planned reclamation for the production and reuse of reclaimed water. The latter would be for the purpose of meeting a particular water resource need as in Los Angeles County. Factors and conditions which justify water reclamation facilities are discussed. The plan developed in southern California should stimulate interest in planning for reuse in other communities that are concerned about their future water resources. The author states, "The question is not whether there will be water reuse, but when, where, and how well it will be implemented."

277. RAWN, A. M., BOWERMAN, F. R. and STONE, RALPH. 1963. Integrating Reclamation and Disposal of Waste Water. *Jour. Amer. Water Wks. Assn.* 55:483-490.

The authors state that, in propounding the need for separating waste water reclamation from disposal, there is danger that the instances in which the two may be integrated will be wholly overlooked. This paper discusses the circumstances which dictate separation and those which permit the integration of waste water treatment and waste water reclamation.

278. Stone, Ralph. 1963. Waste Water Reclaimed for Golf Course Use. *Pub. Works* 94:88-90.

Reclaimed water from the Ontario, California sewage treatment plant is used at the rate of 0.5 mgd for decorative lakes and golf course irrigation. Another 5.5 mgd is diverted to nearby spreading basins for ground water recharge and other irrigation.

Before use on the golf course, the water is retained 30 days in stabilization ponds with 24-hour chlorine contact time and post-chlorination as it is pumped to the golf course.

279. Symposium. 1963. Water Renovation. *Chem. Engr. Progress* 59:19-40.

This series of eleven articles deals with several aspects of water renovation for the purpose of deliberate reuse.

280. Todd, David K. 1965. Economics of Groundwater Recharge. *ASCE Proc.,* 91:HY4:249-270.

Many variables are involved in determining the cost and economic advantage to be gained from artificial recharge of ground water aquifers. Information upon which to base such estimates is scarce. The size, purpose, and method of recharge are significant factors, as are land and water costs. Data from several recharge operations are presented in an attempt to arrive at a logical basis for estimating these costs.

281. Viessman, Warren, Jr. 1965. Developments in Waste Water Reuse. *Public Works* 96:138-140 (April).

The author discusses several possible reuse applications for reclaimed waste water. Among these are irrigation, industrial use, and ground water recharge. Examples of reuse are cited. Consideration is given to the quantities of waste water available and to those operations which this would satisfy economically. The Santee project in southern California is cited as an excellent example of the use of sewage effluent for recreational purposes.

282. Watson, K. S. 1964. Updating Water Resources Thinking to Meet Space Age Requirements. *Water and Sewage Wks.* 111:160-164.

In examining progress in the water resources field, the author considers water management, waste water reuse, advanced waste treatment, desalination, and pollution control, including enforcement.

283. Whetstone, George A. 1965. Reuse of Effluent in the Future with an Annotated Bibliography. *Texas Water Development Board, Austin, Report 8,* December 1965. (187 pp.).

An excellent comprehensive review of the literature dealing with reuse of effluent for purposes of irrigation, recreation, industry, ground water recharge, and potable water supply. There is a total of 663 abstracts dating from 1892 through 1965. The literature reviewed is broad in scope, covering historical development, current status, and unresolved issues in the reuse of effluents. The abstracts are indexed by authors and subject, and are presented in chronological order.

284. YACKEY, HAROLD H. 1961. Future Developments in Water Supply. *Jour. Amer. Water Wks. Assn.* 53:409-412.

The author discusses future water needs and how existing facilities should be expanded to meet these needs. Salvaging waste water is one big step that can be taken.

Author Index

(Figures refer to abstract number)

Abbot, A. L., 4
Agadzhanov, R. A., 232
Alexander, D. E., 261
Allakhverdyants, S. A., 232
Allison, L. E., 134
Anderson, M. S., 116, 122, 123

Babov, D. M., 235
Bachmann, G., 31
Barnette, R. M., 21
Bauer, J. H., 265
Bell, J. W., 143
Bendixen, T. W., 187
Berg, E. J. M., 159, 247
Berger, B. B., 229
Blaney, H. F., 79
Blosser, R. O., 165, 177
Bocko, J., 54, 178, 179
Bohanan, L. B., 55
Bonderson, P. R., 266
Bowerman, F. R., 258, 277
Brown, H. D., 144
Browning, G. M., 80
Bunch, R. L., 267
Bush, A. F., 145
Butler, R. G., 156, 171, 207

Calise, V. J., 243
Canham, R. A., 146, 162
Cannon, D. W., 268
Cantrell, R., 90
Chang, S. L., 254
Cecil, L. K., 269
Chapman, C. J., 81
Chase, W. J., 163
Clarke, N. A., 254
Cleary, E. J., 110
Cohen, J. M., 186
Connell, C. H., 246, 247, 270
Cormack, R. M. M., 82
Crawford, A. B., 198
Culp, R. L., 254

Damoose, N., 101
Dashkova, E. M., 232
Davis, I. F., Jr., 56
Day, A. D., 57, 58, 83, 84, 85, 86
Delano, E. H., 124
Dennis, J. M., 147
Derby, R. L., 248
DeTurk, E. E., 102
Dickson, A. D., 86
Diehl, P. A., 199
Dietz, M. R., 164
Drynan, W. R., 249
Dunlop, S. G., 208, 209, 210, 225, 236
Dunstan, G. H., 148
Dye, E. O., 59, 87
Dziezyc, J., 88

Eberhardt, H., 130
Eldridge, E. F., 136
Eliassen, R., 271
Engelbert, L. E., 34
Ermer, H., 130
Ettinger, M. B., 267

Falk, L. L., 200, 218, 219, 220, 221, 222, 223
Falkenhain, H. S., 211
Feinmesser, A., 91
Fisk, W. W., 180
Fleming, J. R., 125
Fleming, R. R., 272
Forbes, M. C., 270
Frank, A. H., 198
Fries, W., 32
Frodey, R. C., 164

Gallatin, M. H., 73
Gellman, I., 165
Glathe, H., 131
Gloyna, E. F., 249
Goodwin, E. H., 5
Gotaas, H. B., 149
Gray, H. F., 139
Gray, J. F., 89
Greenberg, A. E., 150, 151
Grubinger, H., 33
Guymon, B. E., 250

Halamek, F., 6
Hale, H. H., 144

Handloser, M., 234
Harmon, J. A., 256
Harmsen, H., 212, 230
Harper, H. J., 103
Harrell, R. B., 7
Harvey, C., 90
Hathaway, G. A., 241
Hayob, H., 117
Hedger, H. E., 137
Henry, C. D., 34
Hermann, E. R., 249
Hershkovitz, S. Z., 91
Herzik, G. R., Jr., 231
Heukelekian, H., 60
Hickerson, R. C., 166
Highsmith, R. M., Jr., 92
Hoak, R. D., 242
Hunt, H. J., 35
Husemann, C., 132, 181
Hutchins, W. A., 8
Hyde, C. G., 9

Ippolito, G., 36

Jackson, L. W., 10
Janert, H., 37
Jenkins, D., 183
Jepson, C., 38
Jey, B. N., 232
Johnson, C. E., 167
Johnson, W. E., 61
Jones, J. H., 174
Julen, G., 39

Kabler, P. W., 216
Katko, A., 274
Keating, R. J., 243
Klein, S. A., 183
Kowalski, J., 62
Koziorowski, B., 213
Krey, W., 214
Kruez, C. A., 11, 215
Kuhlewind, C., 118
Kutera, J., 93

Leaver, R. E., 126
Lehmann, A. F., 237
Leukel, W. A., 21
Lowe, R. P., 152
Ludwig, R. G., 138
Luley, H. G., 184
Lunsford, J. V., 148

Maiorova, L. A., 232
Makawi, A. A. M., 131
Maloch, M., 12
Maloy, T. P., 104
Mannering, J. V., 197
Marks, R. H., 273
Martin, B., 244
Mather, J. R., 153
McDowall, F. H., 168
McGauhey, P. H., 151, 183, 207, 251
McKee, F. J., 169
McMahon, E. K., 166
McQueen, F., 239
Mehrotra, C. L., 191
Merrell, J. C., Jr., 70, 274
Merz, R. C., 40, 63, 64, 65, 127, 252, 253
Metzler, D. F., 254
Middleton, F. M., 254, 275
Miller, P. E., 154
Mitchell, G. A., 13, 14, 15, 105
Moldenhauer, R. E., 34
Monson, H., 170
Morgan, J. M., Jr., 119
Morris, S. B., 255
Mulford, S. F., 145
Muller, G., 233
Muller, J. F., 106
Muller, W., 41, 201

Nelson, L. E., 155
Niles, A. H., 107
Norman, N. N., 216

O'Connell, W. J., Jr., 139
Olds, J., 128
Ongerth, H. J., 256
Orlob, G. T., 156, 171, 207
Owens, E. L., 177

Palmer, C. M., 254
Pannier, D., 132
Parkhurst, J. D., 185, 276
Paulsmeier, F., 42, 43
Pearse, L., 107
Peter, Y., 172
Peurifoy, R. L., 140
Phelps, E. B., 142
Pillai, S. C., 16
Pintler, H. E., 274
Pouquet, F., 17
Powell, S. T., 257

Prat, S., 94
Prochal, P., 66

Ragotzkie, R. A., 218, 219, 220, 221, 222, 223
Rajagoralan, R., 16
Rawn, A. M., 202, 203, 240, 258, 277
Reinhold, F., 108
Reinke, E. A., 217
Renshaw, E. F., 67
Reploh, H., 157, 234
Reutlinger, S., 95
Riney, W. A., 18
Robeck, G. G., 186, 187
Rockwell, F. L., 44
Rohde, G., 188
Rudolfs, W., 109, 110, 111, 218, 219, 220, 221, 222, 223

Sanborn, N. H., 158
Sayers, W. T., 186
Seagraves, J. A., 95
Schad, T. M., 259
Scherer, C. H., 260, 261
Schraufnagel, F. H., 189
Schriner, P. J., 112
Schwartz, W. A., 187
Schwarz, K., 45, 46
Scott, R. H., 190
Scott, T. M., 68
Segel, A., 19
Sheets, W. D., 144
Shtok, E. S., 232
Shreier, F., 20
Shuval, H. I., 238
Simmers, R. M., 173
Sisson, D. R., 47
Skinner, J. F., 113
Skulte, B. P., 48, 69
Sladecek, V., 94
Sloan, G., 262
Smith, R. L., 49
Snyder, C. W., 224
Spencer, B. R., 141
Sprivastava, B. P. L., 191
Stanbridge, H. H., 192
Steel, E. W., 159
Steffen, A. J., 193
Stokes, W. E., 21
Stoltenberg, H. A., 254
Stone, A. R., 174
Stone, R., 50, 70, 160, 263, 277, 278
Subby, W., 49
Subrahmanyan, V., 16
Szerszen, L., 178

Talati, R. P., 161
Tanner, F. W., 204
Tatlock, M. W., 114
Taylor, G. S., 182
Thackwell, H. L., 51
Thomas, J. F., 150
Thomson, J. F., 119
Todd, D. K., 175, 280
Tonkin, C. D., 271
Tonty, R. L., 71
Travis, P. W., 72
Troug, E., 34
Tucker, T. C., 57, 58, 83, 84, 85, 86
Trybala, M., 88, 96
Twedt, R. M., 208, 210

Van Kleeck, L. W., 120, 129
Vavich, M. G., 83, 84, 85
Viessman, W., Jr., 281
Vlamis, J., 133

Wadleigh, C. H., 73
Walton, G., 254
Wang, W. L., 208, 210, 225, 236
Warrington, S. L., 226
Watson, J. L. A., 97, 194
Watson, K. S., 282
Webster, R. A., 52
Weiland, K., 227
Weiss, R. W., 195
Wells, W. N., 98, 99
Wesche, J., 181
Westenhouse, R., 196
Whetstone, G. A., 283
Wierzbicki, J., 23, 24, 25, 26, 27, 74, 75, 115, 228
Wilcox, L. V., 28, 73, 76
Williams, D. E., 133
Winslow, C. E. A., 142
Wischmeier, W. H., 197
Woodward, R. L., 186, 187, 254
Wright, C. T., 205
Wycoff, B. M., 271

Yackey, H. H., 284

Zunker, F., 53

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27 *Abstract*
The effluent and sewage sludge from municipal and industrial treatment plants is a source of water and nutrients for agricultural uses. Considering its potential, only a few instances of agricultural uses of waste water in crop production have been recorded. Most of the literature on this subject is by scientists in the sewage disposal field.

This report brings together 284 annotated references on the agricultural uses of sewage effluents and sludge. Such uses aid crop production, but also make use of water that would have been wasted, decrease the pollutant load on the receiving streams, and preserve the normal stream flow for downstream uses. ~~(See EPA)~~ The abstracts in each section are arranged, first, in chronological order (based generally on 5-year periods) and, second, in alphabetical order by author's surname for each chronological grouping. An author index is included at the end~~, of the report.~~ (EPA abstract)

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